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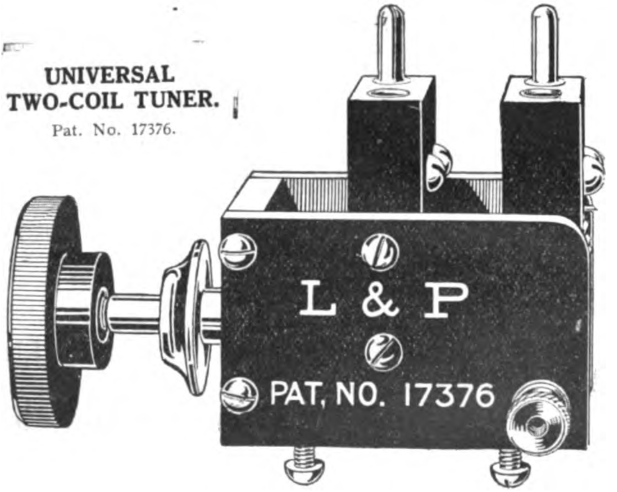

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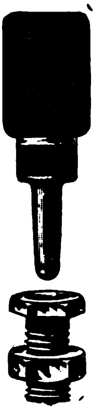

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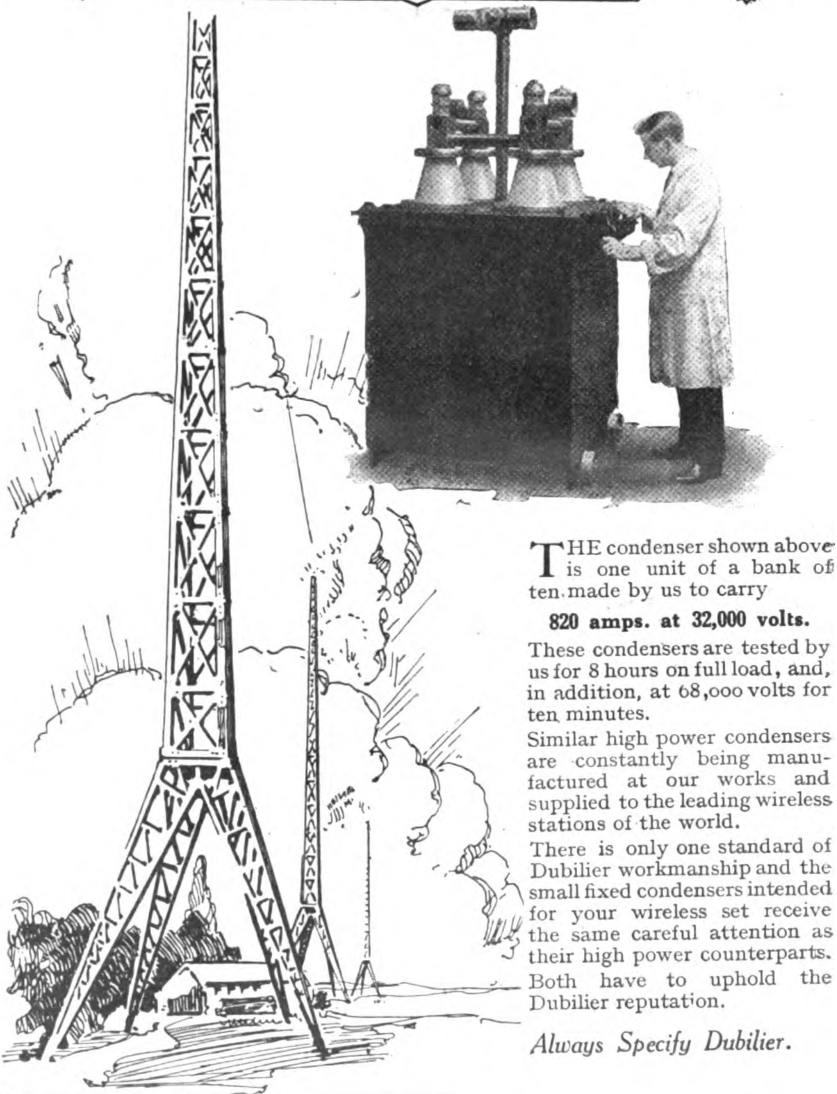

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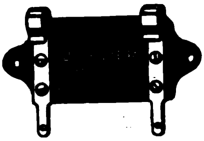

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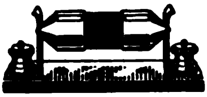

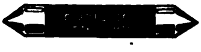

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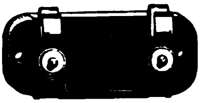

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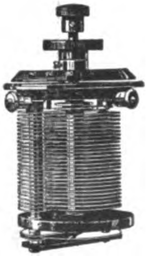

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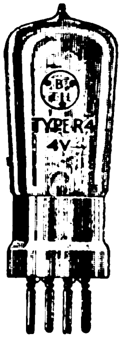

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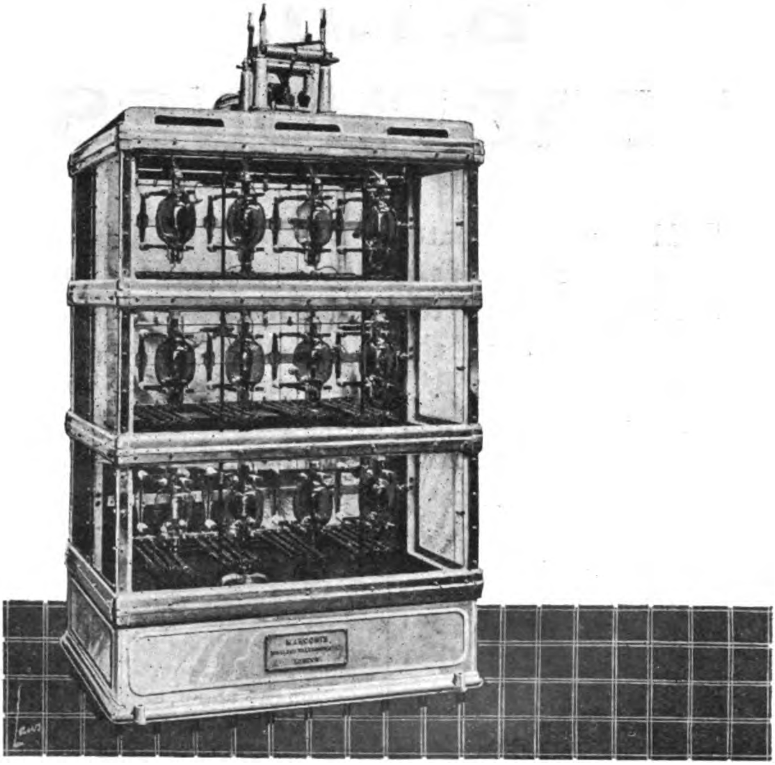

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## TABLE I.

### Symbols for Quantities for use in Electrical Equations, &c.

| Number. | Quantity. | Sign. |
|---|---|---|
| 1 | Length | $l$ |
| 2 | Mass | $m$ |
| 3 | Time | $t$ |
| 4 | Angles | $\alpha, \beta, \gamma$, &c. |
| 5 | Work or energy | $W$ |
| 6 | Power | $P$ |
| 7 | Efficiency | $\eta$ |
| 8 | Acceleration of gravity | $g$ |
| 9 | Revolutions per unit time | $n$ |
| 10 | Temperature, centigrade | $t$ or $\theta$ |
| 11 | Temperature, absolute | $T$ or $\theta$ |
| 12 | Magnetic pole | $m$ |
| 13 | Magnetic field strength | $H$ |
| 14 | Magnetic flux density | $B$ |
| 15 | Magnetic flux | $\Phi$ |
| 16 | Permeability | $\mu$ |
| 17 | Intensity of magnetisation | $J$ |
| 18 | Reluctance | $S$ |
| 19 | Self-inductance | $L$ |
| 20 | Mutual inductance | $M$ |
| 21 | Reactance | $X$ |
| 22 | Impedance | $Z$ |
| 23 | Resistance | $R$ |
| 24 | Specific resistance | $\rho$ |
| 25 | Conductance | $G$ |
| 26 | Voltage (P.D. or E.M.F.) | $V$ or $E$ |
| 27 | Current | $I$ |
| 28 | Capacity | $C$ |
| 29 | Electric charge | $Q$ |
| 30 | Dielectric constant | $K$ |
| 31 | Electrostatic flux density | $D$ |
| 32 | Period | $\tau$ |
| 33 | Frequency | $f$ |
| 34 | 2 $\pi$ × frequency | $\omega$ |
| 35 | Phase displacement | $\phi$ |
| 36 | Decay co-efficient | $b$ |
| 37 | Logarithmic decrement | $\delta$ |
| 38 | Base of Napierian logs | $e$ |
| 39 | Aerial capacity | $\sigma$ |
| 40 | Wave-length | $\lambda$ |

## TABLE II.

### Distinguishing Symbols for Constant and Virtual Values of Quantities.

| Number. | Quantity. | Constant Value. | Maximum Value. | Arithmetic mean Value. | Virtual Value. | Instantaneous Value. |
|---|---|---|---|---|---|---|
| 1 | Voltage | $V$ | $V_m$ | $\overline{V}$ | $V$ | $v$ |
| 2 | E.M.F. | $E$ | $E_m$ | $\overline{E}$ | $E$ | $e$ |
| 3 | Charge | $Q$ | $Q_m$ | $\overline{Q}$ | $Q$ | $q$ |
| 4 | Current | $I$ | $I_m$ | $\overline{I}$ | $I$ | $i$ |
| 5 | Flux | $\Phi$ | $\Phi_m$ | $\overline{\Phi}$ | $\Phi$ | $\Phi$ |
| 6 | Magnetic field | $H$ | $H_m$ | $\overline{H}$ | $H$ | $h$ |

## TABLE III.

### Prefixes for Multiples and Submultiples of Quantities.

| Number. | Multiple or Submultiple. | Name. | Prefix. |
|---|---|---|---|
| 1 | $10^6$ | Mega– | M |
| 2 | $10^3$ | Kilo– | k |
| 3 | $10^2$ | Hekto– | H |
| 4 | $10^{-2}$ | Centi– | c |
| 5 | $10^{-3}$ | Milli– | m |
| 6 | $10^{-6}$ | Micro– | $\mu$ |
| 7 | $10^{-9}$ | Millimicro– | m $\mu$ |
| 8 | $10^{-12}$ | Micro–micro | $\mu$ $\mu$ |

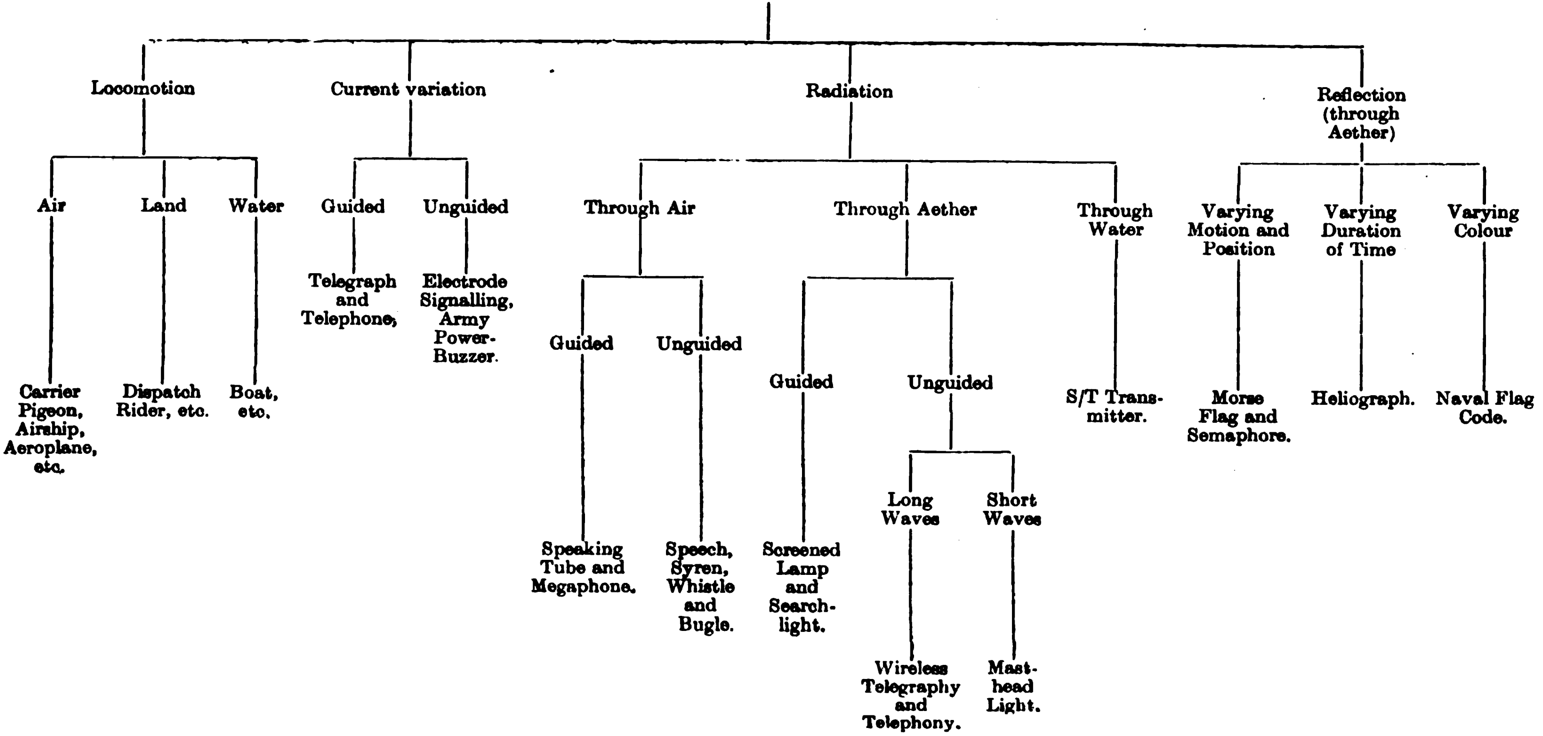
## TABLE IV.

### Signs for Units Employed after Numerical Values.

| Number. | Unit. | Abbreviation. |
|---|---|---|
| 1 | Ampere | A |
| 2 | Volt | V |
| 3 | Ohm | Ω |
| 4 | Coulomb | C |
| 5 | Joule | J |
| 6 | Watt | W |
| 7 | Farad | F |
| 8 | Henry | H |
| 9 | Watt–hour | Wh |
| 10 | Volt–Ampere | VA |
| 11 | Ampere–hour | Ah |
| 12 | Kilowatt | kW |
| 13 | Kilo–volt–ampere | kVA |
| 14 | Kilowatt–hour | kWh |

## TABLE V.

## Modern Methods of Communication.



## CHAPTER I.

**1.** In Wireless Telegraphy or Telephony we deal with the transmission and reception of Electromagnetic or Æther waves. It is the object of this book to explain this means of communication.

**2.** The diagram opposite summarises a variety of methods of communication, the majority of which involve a wave motion of some sort.

Before discussing the production of wireless waves it will be useful to discuss waves in general.

## WAVE MOTION.

**3.** A "**Wave**" is a progressive disturbance in any medium, formed by the propagation of alternating stress and strain through the medium, and not by any actual transfer of the medium itself through space.

Waves are of many kinds, but they all possess certain fundamental characteristics, so that a study of one kind of wave assists us in understanding the properties of others. The waves which occur at the surface of any large body of water possess the advantages that they can readily be seen, and that their movements are sufficiently slow to be easily followed.

If the waves on the surface of the sea are watched, it will be found that they possess the following characteristics:—

(*a*) **The form of the wave** travels forward, although the water itself does not travel forward to any appreciable extent.

(*b*) **The energy** which the wave absorbs from the wind in mid-ocean travels forward with the wave and is expended on the sea shore.

(*c*) **The speed** is the same at any particular spot for all sizes of wave. It depends merely on the depth of the water.

All types of wave possess these three characteristics.

The **number of waves** reaching the shore **in a fixed period of time** is called the **Frequency.**

For the small and rapid waves dealt with in this book the unit of time used is one second, and the **frequency** is the number of waves which reach a particular point in that time.

**The height** of any particular wave above the general level of the sea is called its **Amplitude,** and is a measure of its energy.

**The distance between one wave crest and another** is called the **Wave-length.**

These three terms—**Frequency, Amplitude and Wave-length**—are used in describing waves of all types, and the meaning of the words as applied to water waves will help the student in applying the names to waves of other types.

## SOUND WAVES.

**4.** When a bell is struck with a clapper it is set in vibration at a rate depending on its mass and shape, and the material of which it is made.

Similarly when a piano string is struck, it vibrates at a rate depending on its length, thickness and tension.

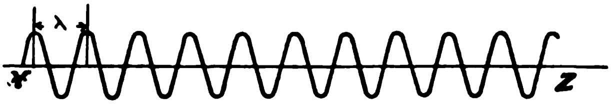
These vibrations set up wave motions in the air.

**5.** All waves may be divided into two classes, viz.:—

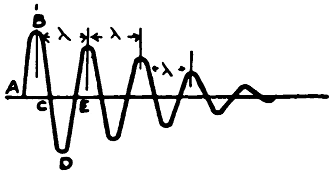
(1) Continuous or "**undamped**" wave trains such as an organ note, Fig. 1 (*a*).

(2) Intermittent "**damped**" wave trains such as a piano note, Fig. 1 (*b*).

(*a*)



*Train of Undamped waves*



*Train of Damped waves*

(*b*)

Fig. 1.

**6.** Wave motions in air consist of alternate states of compression or rarefaction, or to-and-fro movements. They can be represented as in Fig. 1 where distance above or below the line represent compression or rarefaction, and length along the line represents distance between points where various actions are occurring.

In Fig. 1 (*b*) a **cycle** of the wave is shown by the curve A B C D E.

**The wave-length** of the wave is the distance between successive crests as shown. This wave-length is generally indicated by the symbol "$\lambda$".

**The amplitude** of the first half cycle is the height of the point B above the horizontal line. This amplitude diminishes as the wave travels and loses energy, until the wave eventually becomes too feeble to be detected.

As regards the wave shown in Fig. 1 (*a*), 10 complete waves are shown between the points Y and Z. If these 10 waves were given off in one second, the wave depicted would be said to have a **frequency** of 10 cycles per second.

**7.** The method used in Fig. 1 of indicating a quantity varying periodically should be noticed. The portions of the curve above the horizontal line are termed positive half cycles, and the portions below, negative half cycles. The use of the words positive and negative does not mean that these half cycles are different in nature, as it does when we speak of positive and negative electricity: it only means that the action is taking place in opposite directions.

The horizontal line is termed the zero or neutral line.

Distances measured along the line represent time. Curves of this nature are used to represent variations of current, voltage, electric stress, etc.; in this case the curve represents variations of air pressure.

**8.** The frequency of sound waves is also termed "**Pitch.**"

Doubling the frequency of a sound wave raises it one octave. For example, the middle C on a piano, tuned to "Scientific Pitch," has a frequency of 256, the next higher C a frequency of 512, and so on.

It does not follow that all sound waves are **audible.** The best known form of sensitive receiver for sound waves is the human ear. The ear will only respond to—or take account of—a very limited range of pitch.

The lower limit of audibility is about 16 cycles per second, while the upper limit varies from about 20,000 to 30,000 cycles per second, according to the person concerned.

The piano has a range of pitch from 27·2 to 4,138·4.

The pipe organ usually has 16 for the lowest pitch and 4,138 for the highest pitch.

The range of pitch for the human voice in singing is from 60 for a low bass voice to about 1,300 for a very high soprano.

**9.** Sound waves, unless specially directed, as with a megaphone, or reflected, as in an echo from a cliff, travel outwards from the source in all directions, like the ripples caused on the surface of a pond when a stone is thrown into it.

They move at a certain speed or velocity, which in air may be taken at 1,132 feet per second, or about 13 miles per minute.

**10. Wave-length.**—If their frequency is known, their wave-length may be easily determined.

This wave-length $\lambda$ obviously depends on the frequency of the wave and the speed with which it is travelling, for if it is travelling at " $v$ " feet per second, and " f " wave crests are propagated per second, the distance ($\lambda$) between one wave crest and the next will be $\frac{v}{f}$ feet. For example, the wave-length of the middle " C " referred to above will be $\frac{1,132}{256} = 4 \cdot 42$ feet, while that of the treble " C " will be $\frac{1,132}{512} = 2 \cdot 21$ feet.

**11.** Sound signals produced in air are very erratic in their range and intensity—so much so as to be on many occasions absolutely misleading.

This is due to the fact that sound may be carried by the wind or may be reflected or refracted (bent from its course) by layers of air of different densities, with the result that a sound may be audible many miles away, while there may be a zone of complete silence extending from a few hundred yards in front of the signal to a distance of four or five miles.

**12.** Sound waves may also be propagated **through water,** as is done by the Fessenden transmitter.

They travel at a higher speed in water, as their speed of travel varies with the density and elasticity of the medium employed, *e.g.*, in fresh water, sound waves travel at 4,700 feet per second, and in sea water, at 4,900 feet per second.

The wave-length of the middle " C " in water would be $\frac{4,900}{256} = 19 \cdot 14$ feet.

Sound waves in water can be received on a suitable receiver, such as a hydrophone, an S/T oscillator, or even through the hull of a ship.

## THE ÆTHER.

**13.** In the foregoing instances of wave motion, viz., surface sea waves and sound waves, the wave motion has depended on some movement of matter (para. **24**) at the source.

There are other sorts of wave motion or vibration, called " æther waves," which are generated by the movement of electrons at their source.

Now we have seen that sound is conveyed from transmitter to receiver in the following manner:—the transmitter is set in vibration; the intervening medium is set in vibration; the vibrations of the medium set the receiver in vibration.

We are led to believe in the existence of a medium we term the Æther for the following reasons:—

The earth continually receives enormous quantities of energy from the sun in the form of light and heat, which travel through a space known to be empty of ordinary matter. Filaments of incandescent lamps give off light and heat although the bulb contains practically no gas or air.

It is unreasonable to suppose that the energy in the sun or in an electric circuit disappears there and reappears at the earth (or the receiving circuit) without having been conveyed across the intervening space.

It must be conveyed across either as an actual molecular movement, like the flow of a river, or as a wave motion, like the passage of sound through air.

All experience goes to show that light and electro-magnetic energy generally are transmitted through space as a wave motion, and we are led to the supposition that all space is occupied by a medium which conveys the energy, and that this medium has properties different to those possessed by ordinary matter.

We call this medium " Æther."

The medium called the Æther must necessarily be universally diffused, and must inter-penetrate all matter. It cannot be exhausted or removed from any place, because no material is impervious to it.

The presence of what we know as matter in its various forms may, however, modify the properties of Æther so far as these Æther waves are concerned.

For example, a light wave can pass through a glass window but cannot pass through a brick wall, while a wireless wave can pass through a brick wall but cannot pass through a sheet of copper.

The Æther must possess in great degree some form of elasticity —that is, resistance to any change of state produced in it— and it must also possess inertia, or a quality in virtue of which a change so made in it tends to persist.

It is clear that it has the property of being capable of storing up energy in large quantities and transmitting it from one place to another, as shown by the fact that enormous amounts of energy are hourly being transmitted from the sun to the earth.

Vibrations of the æther are *only* produced by the electric and magnetic fields associated with electrons (*see* Chapter II.).

Electric and magnetic stresses and strains are passed through the æther with a definite velocity, which has been found to be ***300,000 kilometres, $3 \times 10^8$ metres,** or **186,000 miles per second.**

All movements of the æther consist of electric and magnetic forces alternating in direction: they produce a disturbance, spreading outwards, which is called an " electro-magnetic wave, or simply an " Æther Wave."

**14. Æther Waves.**—Now these æther waves or rays produce different effects and require various methods of reception according to their frequency and wave-length.

The principal æther waves are shown in Table VI.

Energy is conveyed by all these waves, and can be made perceptible as heat by means of a suitable detector.

They do not affect the ear directly, and cannot be heard.

---

* This figure is an approximation. The figure which is generally accepted as being accurate is $2 \cdot 9982 \times 10^8$ metres per second.

Each group on the chart represents merely different frequencies of æther vibration, the speed of travel being the same in each case.

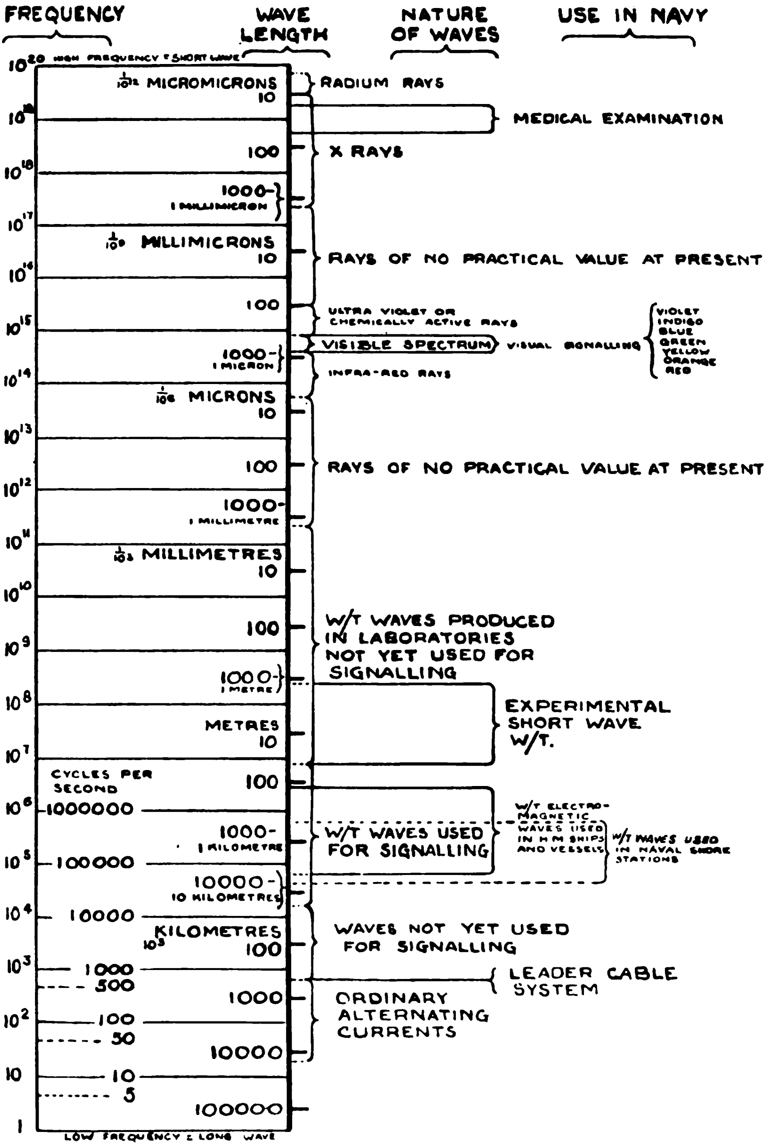
The first group on the chart is that of the radium rays, sometimes used in the treatment of cancer.

Then come the X-rays used in medical examinations.

Then comes a range of waves which are put to no practical purpose at present.

TABLE VI.

## WAVES IN ÆTHER.



Then come the rays of the spectrum—rays which can be detected by the eye. The different colours of the spectrum are merely different frequencies of æther vibration. When blended together they give the effect of white light. Conversely, a ray of white light may be split up into the colours of the spectrum, *e.g.*, if passed through a prism.

Then comes another series of waves of no practical value at present.

Then come Wireless or Hertzian Waves, ranging in length from about 5 metres to 30 kilometres.

They are of too low a frequency to be made perceptible directly by the eye, and have to be collected on an aerial, and then made perceptible to the senses in one of a variety of ways —generally by giving rise to sounds in a pair of telephones.

They have the supreme advantages over any other form of signalling that they follow the curvature of the earth, and do not suffer nearly so much from dissipation in the atmosphere, and so are suitable for signalling to the greatest possible distances. It is only a question of the use of suitable power and receiving gear for stations to communicate with half the circumference of the earth between them.

**15.** For a proper understanding of W/T, the main essential is a thorough grasp of the principles of electricity, and of the laws governing alternating and direct currents. Once these are mastered, W/T in itself will be found to be easy of comprehension, provided the student has some imagination, since one is dealing with a wave motion which is invisible, inaudible and intangible.

The problem in W/T is to maintain an electrical oscillation in an aerial circuit.

The nature and appearance of an aerial may be assumed to be familiar to everyone nowadays.

An aerial circuit is a natural electrical oscillator.

In virtue of certain properties termed "inductance" and "capacity," which are associated with it, it is just as ready to be set in electrical oscillation as is the balance wheel of a watch to be set in mechanical oscillation.

**16.** The balance wheel of a watch is such a very useful and accurate analogy all through the study of W/T that we may well stop for a moment to consider it.

The wheel is carefully balanced and mounted in perfect bearings. To its centre is attached one end of a fine spring—the "hair spring."

The tension on this hair spring is adjustable by means of the "regulator."

The balance wheel oscillates at a rate depending on its weight and the tension on the hair spring.

In its oscillation, it operates the escapement which controls the rate at which the main spring is allowed to uncoil and move the hands of the watch: conversely, the main spring supplies the energy requisite for maintaining the oscillation of the balance wheel.

Now the weight or inertia of the wheel and the elasticity of the mainspring are two mechanical properties which correspond respectively to the electrical properties of the aerial referred to above—**inductance and capacity.**

The aerial circuit may be thought of as the balance wheel and the various systems of energising such a circuit described in this book as the mainspring and escapement.

**17.** The four methods employed for the transmission of W/T are :—

(*a*) The spark system.
(*b*) The arc system.
(*c*) The valve system.
(*d*) The high frequency alternator system.

Method (*a*) generates damped waves.

Methods (*b*) and (*d*) generate undamped or continuous waves : method (*c*) generates damped or undamped waves at will.

In the Naval service we are not concerned with the high frequency alternator system.

**18.** The relative merits of these four systems may be classified as follows :—

### (*a*) The Spark System.

| *Advantages.* | *Disadvantages.* |
|---|---|
| (1) Robust and durable. | (1) Wasteful of power. |
| (2) Faults easily cleared. | (2) Short range as compared with continuous wave generators. |
| (3) Emits a wave which forces its way well through interference. | (3) Interferes badly. |

### (*b*) The Arc System.

| | |
|---|---|
| (1) Robust and durable. | (1) Slow in starting up. |
| (2) Faults easily cleared. | (2) Presents certain "keying" difficulties. |
| (3) Can be easily constructed to handle large powers. | (3) High power sets radiate harmonics badly. |

### (*c*) The Valve System.

| | |
|---|---|
| (1) Radiates a very pure wave. | (1) Valves are fragile and require frequent replacement. |
| (2) Easy to key. | (2) If faults develop, they are not so easy to trace as in other sets. |
| (3) Very suitable for radio-telephony. | |
| (4) Transmits damped or undamped waves at will. | |
| (5) Quick in starting up. | |

### (*d*) The High Frequency Alternator System.

| | |
|---|---|
| (1) Radiates a wave which is very pure and free from harmonics. | (1) Requires very expert supervision and maintenance. |
| (2) Easy to key. | (2) Its wave length cannot be varied so readily as in other systems. |
| (3) Very suitable for radio-telephony. | (3) Its first cost is high. |
| (4) Suitable for high power working. | |

The first three systems are described fully in subsequent chapters.

**19.** When the aerial circuit is set in oscillation by one of the above methods, a succession of waves is set up in the æther, of a frequency too high to affect the senses, as is indicated in Table VI.

These waves spread out in all directions over the surface of the earth, in circles of ever-increasing radius.

Whenever they encounter any other aerial, they endeavour to set it in electrical oscillation, as the wind sets trees shaking.

The most vigorous oscillation is established in those receiving aerials which possess the same combination of inductance and capacity as that of the transmitting aerial circuit, which generates the oscillation.

The currents in the receiving aerial are passed through a "detector," which renders them suitable for energising a device—a pair of telephones, a loud-speaker, a tape-machine, etc.—which renders them perceptible to one of the senses.

**20.** Notice the sequence—the transmitter—the intervening medium—the receiver.

In the same way, in speaking, the transmitter is the human throat and mouth, the medium which carries the sound waves is the air, the receiver is the drum of the ear.

In signalling with a flashing lamp, the transmitter is the lamp, the medium is the aether which carries the light waves, the receiver is the eye.

**21.** Further, wireless may be used for telephony. The only difference is that the human voice is passed through a microphone in order to vary or modulate the aerial current, instead of using a morse key. The wave is carried to the receiver and detected in the same manner as above.

The direction from which a wireless wave is coming may be determined by the use of "direction-finding" apparatus. This is of very great benefit in navigation, and is dealt with in a subsequent chapter.

We must now proceed to discuss electricity in general, direct and alternating currents, and the machinery required for producing them, before getting on to the details of the various transmitting and receiving circuits used in wireless telegraphy.

## CHAPTER II.

## ELECTRICITY AND MAGNETISM.

**22.** In this chapter the elementary principles of electricity and magnetism are explained, in so far as they affect wireless telegraphy and the circuits used in wireless telegraphy.

The explanations must necessarily be very brief and a large library could be easily be written on the subjects dealt with here.

The first thing requiring explanation is the nature of electricity itself, as we understand it.

**23. The Modern Theory of Electricity.**—The nature of electricity is not really understood, any more than is the nature of thought. A great deal more, however, is known now than was the case ten years ago, and fresh discoveries are being made every day.

The modern theory of electricity is termed "The Electronic Theory." This is not so difficult to understand as it sounds, and is of the greatest possible help in explaining the action of valves and many other electrical phenomena.

It would be idle to pretend that we have as yet any theory of the structure of the atom which absolutely and completely sums up all known facts concerning electricity.

Scientists may form a mental picture of an atom to help them to explain one electrical phenomenon which may be quite inaccurate for dealing with another problem, and a new mental picture of the atom may have to be adopted.

The reader must also realise that it is impossible to indicate in a few paragraphs all the difficulties and limitations met with in the study of "molecular physics": but a brief summary of some of the modern conceptions of the constitution of atoms may enable him to get a good idea of what is occurring.

**24. Matter** is anything—except the æther—which occupies space. Anything which has weight and size is matter. Some kinds of matter are invisible—for example, pure air, coal gas, oxygen, &c.—but since they occupy space and have weight they are matter.

**25. The construction of matter** is fairly well understood. Matter is composed of myriads of distinct or separate material particles, with spaces between them. These particles are termed **molecules.**

There are as many different kinds of molecules in the universe as there are different kinds of substances—an almost limitless number.

A molecule is the smallest portion of any substance which cannot be subdivided further without its properties being destroyed. It is the smallest complete and normal unit of any substance.

**26. The Atom.**—The molecules are made up of smaller particles called **atoms.** An atom is the smallest particle into which matter can be divided by chemical separation.

A molecule may consist of one, two, or more atoms of the same kind or it may consist of two or more atoms of different kinds. Thus two atoms of hydrogen (H) will combine to form a molecule of hydrogen ($H_2$). Two atoms of hydrogen and one atom of oxygen will combine to form a molecule of water ($H_2O$).

The number of atoms in a molecule varies with the substance. In a molecule of salt there are two atoms, in a molecule of alum there are about 100 atoms, &c.

Different kinds and combinations of atoms can be arranged in an endless variety of ways to form different substances—different kinds of matter.

It is believed that there are no more than 92 different kinds of atoms, and molecules of all known substances consist of combinations of these atoms.

**27. The Electron.**—It is believed that **Atoms are made up of minute particles of negative electricity**—termed "**Electrons**"—and of a central nucleus in which practically the whole mass of the atom resides.

**This nucleus is positively charged** as a whole, and the mass of the nucleus is most probably due to the charge which it carries.

Outside this nucleus, and probably at comparatively considerable distances from it, are sufficient negative electrons to make the system as a whole electrically neutral, the positive charge of the nucleus being neutralised by the negative charges of its attendant electrons.

**28.** An electron is a particle of electricity free from association with anything in the nature of matter as we know it. It not merely has a charge, **it is a charge,** and apart from its charge has no existence and no properties, not even that of mass.

The charge it carries is equal to $1 \cdot 57 \times 10^{-19}$ of a coulomb, the unit of electrical quantity. Conversely, there are approximately $6 \times 10^{18}$ electrons in a coulomb.

**29.** The radius of an electron is $1 \cdot 87 \times 10^{-13}$ cm. This is so exceedingly small that it is impossible to form any mental picture of it.

If a drop of water were magnified to the size of the earth its **atoms** would be about the size of footballs.

Now the **electrons** are so small compared to the atoms they go to make up that they occupy the same proportional space in them as a fly does in a cathedral.

**30.** The number of electrons in the universe is constant and unvarying. Electricity can neither be created nor destroyed.

Electrons can, as is shown later, be set in motion and caused to move from one location to another, thus producing what are known as electrical phenomena.

But electricity—electrons—can be neither made nor eradicated.

It is therefore evident that electricity can be neither "produced" nor "generated," in spite of the fact that the term "generation of electricity" is frequently used. When the statement is made that "electricity is generated by a battery or a dynamo" what is really meant is that the battery or dynamo forces some of this electricity, which is already in existence, to move.

It exerts an Electro-Motive Force (E.M.F.).

A battery or dynamo does not generate electricity in the wires connected to it any more than a pump, which is impelling a stream of water in a pipe, generates the water.

**31. Construction of Atoms.**—One conception of an atom is as a nucleus charged with positive electricity, around which revolve in fixed orbits negative electrons, as planets round a central sun.

Fig. 2 is a very diagrammatic representation of this idea.

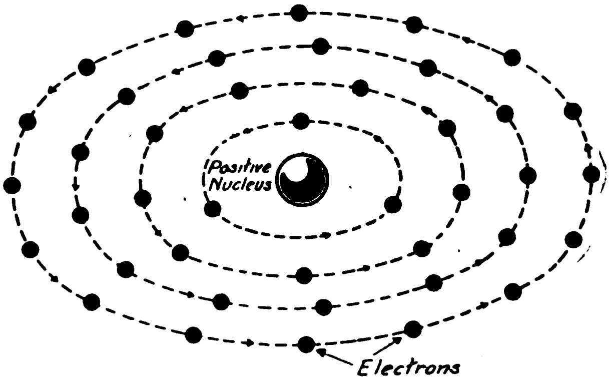


Fig. 2.

An atom is thus pictured as comprising from one to a number of electrons which are interlocked and revolving at inconceivably great speeds in regular orbits around the positive nucleus. Thus it is apparent that energy is associated with and locked up in every atom.

The nucleus may be thought of as a charge of positive electricity concentrated at a point, at the centre of the atom, around which the electrons—restrained in their orbits by it—revolve.

We know very much less about the positive nucleus than we do about the electron. It may consist of several positive units of charge—or **positive electrons**—locked together in some manner by the help of negative electrons, but the nucleus as a whole must have a positive charge in order to hold the atom together.

**32.** The number of electrons in an atom varies with the kind of atom, as does also the value of the positive charge of its nucleus; that is, the heavier atoms comprise many more electrons than do the lighter ones. In fact, it is possible that the number of electrons in an element is proportional to the number representing the atomic weight of the element.

Thus, the atomic weight of hydrogen, the lightest known element, is about 1, and it is probable that there is but 1 rotating electron in an atom of hydrogen.

NOTE.—Hydrogen, being the lightest gas known, is taken as a standard to which all other gases are compared, and its atomic weight may be taken as unity.

Vanadium, which is about 51 times heavier than hydrogen, probably contains 23 electrons.

Zinc, with an atomic weight of 65·37, probably contains 30 electrons.

The number of electrons in an atom is equal to about half the atomic weight of the atom (except in the case of hydrogen).

**33. Molecules** in matter are always on the move—they are oscillating and quivering constantly. They cannot—even in a good vacuum—travel far without bumping into neighbouring molecules. It has been estimated that in the ordinary air every **molecule** collides with another about six thousand million times per second.

No two molecules are in permanent contact with each other. An inconceivably small space separates each molecule from its neighbours. Every molecule is, at ordinary temperature, quivering and oscillating to and fro—many million times per second—in its small restricted space between its fellows.

Owing to these movements, the electrons in the molecules set up disturbances in the æther, which disturbances constitute what we know as "heat."

If a body is warmed, its molecules vibrate more actively. They pound harder on the adjacent molecules and thereby push them away. This makes the body become larger as it is warmed.

**34. There are three states of matter.**—Solid, liquid and gaseous.

**In solids,** the motion of each molecule is like that of a man in a dense crowd, where it is almost or quite impossible for him to leave the space he occupies between his neighbours; yet he may turn round and have some motion from side to side.

In solids the attractive force between molecules is very great; it requires considerable pressure to alter the shape of solids.

**In liquids,** the motion of the molecules is like that of men moving in a crowded thoroughfare. The attraction between molecules is relatively small—the cohesive force is almost lost; hence liquids will assume the shape of a vessel into which they are poured.

**In a gas** the molecules are thought to be in motion like a swarm of midges in air.

There is practically no attraction between molecules in a gas—the cohesive force is almost entirely absent—they are bounding and travelling round endeavouring to knock one another apart.

(Everyone knows how, if a bottle of some gas with a strong smell is opened in a room, the smell rapidly spreads and fills the whole room.)

Thus water molecules ($H_2O$) may exist in (*a*) a solid state, viz., ice; (*b*) a liquid state, viz., water; (*c*) a gaseous state, viz., steam.

In the change of matter from one state to another, the molecules themselves are not changed, it is merely the spacings between and the spaces occupied by the molecules in their vibrations and wanderings that have been changed.

**35. Ions and Ionization.**—Certain substances possess, in addition to those electrons which form part of their essential structure, other electrons which may be detached from, or attached to, the atom, without in any way altering its nature. These "spare numbers" are termed **"mobile electrons."**

The presence or absence of these mobile electrons in a substance determines the properties of the substance as a conductor or insulator.

As previously stated, every normal atom comprises a certain number of electrons in combination with positive electricity just sufficient to neutralise the negative effect of the electrons.

Normally, atoms exhibit no electrical properties, because the positive electricity in them neutralises the negative.

But if an atom has an electron too many, or an electron too few, then it does exhibit electrical properties, which can be detected by the electrostatic attractive and repulsive effects thereby produced, and the atom is then said to be ionised.

Thus when an electron is taken from or added to a previously neutral atom or molecule, the charged particle which is thus formed is called an **ion.**

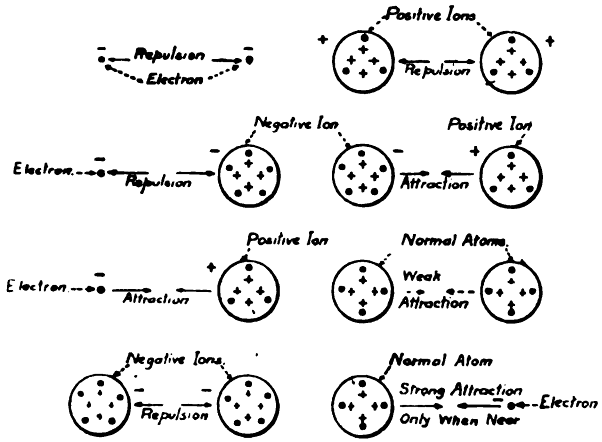
The process is called **ionization.**

In other words an ion is what is left after an electron has been knocked from a neutral atom or molecule, or, an ion is what exists after an electron is added to a previously neutral atom or molecule.

If an electron is knocked from a normal atom, the atom then becomes a **Positive Ion,** having a deficit of negative charge.

If an electron is added to a normal atom, that atom then becomes a "**Negative Ion**" having a surplus of negative charge.

**Fig. 3** illustrates diagrammatically the attraction or repulsion between **electrons** and positive or negative ions.



*Forces exerted between Electrons and Ions.*

FIG. 3.

A positive ion is indicated diagramatically as having four units of positive charge and three units of negative charge.

A negative ion is similarly shown with four positive units and five negative units.

Their mutual attractions or repulsions are indicated by the directions of the arrows.

Thus two electrons, two positive or two negative ions repel each other; a negative ion repels an electron. A positive ion attracts a negative ion, and an electron. There is weak attraction between normal atoms, and strong attractions between a normal atom and an electron when they are near.

**36. Positive and Negative Electrification.**—When there is an excess of electrons associated with any body it then acquires certain properties and is said to be negatively charged.

When a body has associated with it less than the normal number of electrons, it has certain other properties and is said to be positively charged or electrified.

Electron currents always flow from the "Negative Pole" to the "Positive Pole," in spite of the fact that it is usually assumed that "electricity" flows from positive to negative. This unfortunate state of affairs is due to the fact that the pioneer electrical experimenters arbitrarily named an electrification involving **a deficit of** electrons a **positive** electrification, before the nature of electricity, as we understand it now, was appreciated. When a " Negative Pole " is spoken of, a surplus of electrons is meant; when a " Positive Pole " is spoken of, a deficit of electrons is meant.

This is the only real difficulty involved in the electron theory. As most readers of this book are used to the assumption that current flows from positive to negative, this will be adhered to in arguments and diagrams, but special attention will be drawn to the actual direction of the electron current in places where it is important, such as in the description of cells, of the Poulsen arc, and of transmitting and receiving valves, &c.

**37. Electric Currents, Conductors and Insulators.**—Solids are divided into two classes—"**Conductors**" and "**Insulators**"—according as they do or do not conduct electricity.

We have by now come to connect electricity with electrons, and hence an electric current is a flow of electrons between two points of differing potential.

We may regard a conductor, then, as a substance containing electrons which are free to move under the action of an electric field, while in non-conductors the electrons are fixed and unable to follow the impulse of the field, although they can be slightly displaced.

How are these electrons set free in a conductor?

In the first place it may be noticed that the only good conductors of electricity are metallic substances, the atoms of which will **readily part with an electron,** under the slightest provocation.

Now in such a solid such provocation may well be supplied by the nearness of neighbouring molecules.

It is well known that a charged body attracts light uncharged substances. The attraction of a glass rod well rubbed with a silk handkerchief for small pieces of paper is generally our first introduction to the science of electricity.

The reason is that mobile electrons are rubbed off the glass rod, which is left with a deficit of electrons, or positively charged. These electrons appear on the handkerchief, which becomes negatively charged.

Hence an electron in one atom is attracted by a neighbouring uncharged atom, and in the case of an atom only too ready to part with its electrons, the attraction may well be sufficient to enable it to make its escape under favourable circumstances.

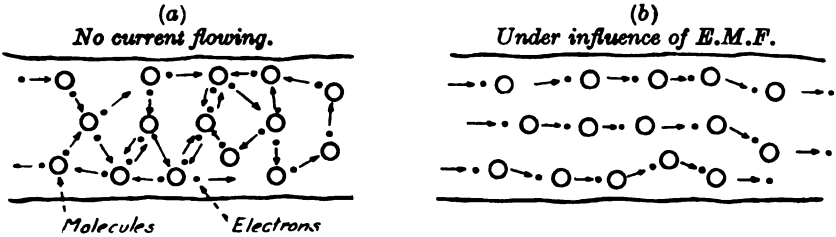
Thus a conductor, **when not acted upon by an E.M.F.,** may be looked upon as composed of molecules from which electrons are continually escaping for a moment.

These electrons, if no electric force be acting, will be moving in all directions, so that if we take any cross-section of the metal the number of electrons crossing it in one direction will be the same as the number crossing it in the other direction, and so the total transference of electricity across the section will be zero (Fig. 4 (*a*) ).

For a given substance at a given temperature there will be a definite pressure of electrons per unit volume in the metal, and we may in fact look upon the electrons as a kind of thin gas filling up the interstices between the molecules of the solid.

If, however, **we apply an E.M.F.** to the body there will be a force on each electron urging it in the direction of the E.M.F.

Thus, in addition to the heat energy of the body, there will be a steady drift of the electrons as a whole in the direction of the electric force (Fig. 4 (*b*) ).



*A Conducting Substance.*

FIG. 4.

Fig. 4 (*a*) is an attempt to illustrate the conditions prevailing in a metal conductor when not acted upon by an E.M.F. and shows a number of electrons darting in and out of the molecules in all directions.

Fig. 4 (*b*) illustrates the same conductor when acted upon by an E.M.F., and shows the electrons all moving in the same direction.

It must not be imagined that any given electron will travel the whole way round a circuit. It will only travel a very short way before it encounters and unites with a molecule, but the molecule will promptly liberate another electron, which will move on in the same direction as the first.

It will be observed that the conductivity of a substance depends solely on the number of electrons which are normally free from molecules at any given instant.

The best conductors are those substances whose molecules carry the greatest number of mobile electrons.

**Insulating substances** or **Dielectrics** are believed to be those substances in which the electrons are held tightly bound in the atoms. Electric conduction currents cannot flow readily in an insulating substance—because its electrons cannot move from atom to atom. Remember that there can be an electric current only when electrons are moved.

Conduction is thus a matter of degree. The tighter the grip of the nucleus on the electrons, the lower the conductivity of the substance. This grip, however, is somewhat elastic, and not absolutely rigid; the electrons when under the influence of an E.M.F. can sway about inside the atom without actually leaving it.

Thus when an E.M.F. is applied, all the electrons are strained in one direction, and transference of energy does occur through the insulating medium.

Thus the difference between good and bad conductors, or bad and good insulators, is in the readiness or otherwise with which their atoms will liberate and pick up electrons.

If, on an E.M.F. being applied, electrons are transferred readily from one atom to another, the substance is a good conductor.

If the same E.M.F. is applied to another substance, and only a very few electrons are transferred through the substance, the substance is a bad conductor.

If no electrons are moved out of their atoms at all, the substance is a perfect insulator.

For example, silver, copper, gold, aluminium and zinc are good conductors; linen, cotton, wood, stone and ivory are poor conductors; dry air, glass, indiarubber, shellac, silk and oil are good insulators, or very bad conductors.

**38. Electric Current.**—An electric current is defined as electricity in motion. Whenever electricity is moved this movement constitutes an electric current.

There are three well defined types or classes of electricity movement, and therefore three different sorts of electric currents.

They are :—

(*a*) Conduction Currents.
(*b*) Displacement Currents.
(*c*) Convection Currents.

**39. A Conduction Current** is an electric current which will flow **in a conductor** which forms a closed circuit, if some source of E.M.F. is inserted in that circuit. As long as the E.M.F. is impressed on the circuit the conduction current will flow.

The explanation of a conduction current on the basis of the electron theory is very much as illustrated in Fig. 4, and explained in para. **37.**

**40. A Displacement Current** is a current that flows momentarily **in a dielectric or insulating material** when an E.M.F. is impressed across that material, or when an E.M.F. impressed on that material is changed in intensity.

When an E.M.F. is impressed across a piece of insulating substance a charging or capacity current will flow momentarily in the direction of the E.M.F. This is because the electrons in the atoms are being strained in one direction, and the atoms allow a certain movement of the electrons but do not permit them to move from one atom to another.

The electron movement ceases as soon as the E.M.F. reaches a steady value; if it is increased or decreased the electrons are either strained a little further or allowed to return a little to their normal position.

Thus a displacement current only flows when the applied E.M.F. is increasing or decreasing.

So long as the impressed E.M.F. is continued, without variation in intensity, across the insulator, the dielectric will remain in a state of strain.

**41. Convection Currents** are those currents which are due to the movement of electricity—electrons or positive and negative ions—through a liquid or a gas, viz., through the electrolyte of a cell (p. 33), across a spark gap or a Poulsen arc (p.267) between the filament and anode of a valve (p. 312), &c. In each case an "ionising" action occurs. They will be fully dealt with in the chapters on these subjects.

**42. Definitions and Units.**—We will now proceed to define the units in ordinary electrical language. Just as the yard is the British standard of length—it is the length of a certain piece of metal kept in the Standards Office of the Board of Trade—so in electricity it is necessary to have certain well defined units, on which all calculations may be based.

The units used throughout this book are the units used in ordinary practice.

These units are based on the "absolute electro-static" or "absolute electro-magnetic" units, which are the units used by scientists. A description of these absolute units is given in Appendix C (p. 521).

## UNITS.

**43. Resistance**—denoted by the letter "R"—is the property of matter of opposing the passage of electrons through it; or, the property of converting the energy of the swiftly moving electrons into heat. It may be compared with friction that is encountered by all moving bodies.

The less the willingness with which molecules receive and release electrons, the greater is the shock given to the atom, and consequently to the molecule, the greater the oscillation of the molecule and the greater the heat generated.

The standard definition of the **Ohm**, the unit of resistance, is the "resistance of a column of mercury 106·3 cms. long, 1 sq. mm. in cross section and of a mass 14·4521 grammes at a temperature of melting ice." But most of us probably form a much clearer conception of its value by thinking of the lengths of standard copper cables or wires with which we are familiar.

The ohm is the "practical unit," but it may also be expressed in "absolute or electro-magnetic units."

1 ohm (symbol $\Omega$—omega) $= 10^9$ electro-magnetic (e.m.) or absolute units (*see* Appendix C).

1 megohm (symbol $M\Omega$) $= 10^6$ ohms $=$ a million ohms.

1 microhm. (symbol $\mu\Omega$—mu omega) $= \frac{1}{10^6}$ or $10^{-6}$ ohm $=$ a millionth of an ohm.

**44.** The "**specific resistance**" of a conductor is the resistance of an inch cube or cm. cube between opposite faces. Tables of the specific resistances of various conducting substances are made out usually at 0° C. temperature since resistance alters with a change of temperature. The specific resistance of a conductor being known, also its length and cross-sectional area, its total resistance is easily calculated from the formula—

$R = \frac{\rho l}{a}$, where $R$ = resistance in ohms.

$\rho$ = specific resistance in ohms per cm. cube.
$l$ = length in cms.
$a$ = cross-sectional area in square cms.

Some specific resistances are, approximately :

| | |
|---|---|
| Copper - - | 1·7 microhms per cm. cube. |
| Platinum - - | 11 ,, ,, |
| Mercury - - | 94 ,, ,, |
| Distilled water | $7 \times 10^{18}$ ,, ,, |

**Example 1.**

**Find the resistance of a copper conductor 5 miles long and 0·08 ins. in diameter.**

**The first thing to do is to reduce the various lengths employed to the same unit before applying the formula.**

$$5 \text{ miles} = 5 \times 1{\cdot}61 \text{ kilometres.*} = 8{\cdot}05 \times 10^5 \text{ cms.}$$

$$\text{The area of the conductor} = \pi \times {\cdot}04^2 = 3{\cdot}1416 \times {\cdot}0016 = {\cdot}005026 \text{ sq. in.} = {\cdot}005026 \times 6{\cdot}45 \text{ sq. cms.*} = {\cdot}03242 \text{ sq. cms.}$$

$$\rho = 1{\cdot}7 \times 10^{-6} \text{ ohms per cubic centimetre.}$$

$$\text{Therefore } R = \frac{1{\cdot}7 \times 10^{-6} \times 8{\cdot}05 \times 10^5}{{\cdot}03242} = \frac{1{\cdot}37}{{\cdot}03242} = 42\,\Omega \text{ approx.}$$

**45. Conductivity,** or conductance, is the property a body possesses of conducting the current, being obviously just the opposite to resistance. Conductors have both resistance and conductivity. The unit " mho "—*i.e.*, " ohm " spelt backwards—has been suggested but is not generally in use; it is equal to

$$\frac{1}{\text{No. of ohms' resistance.}}$$

**46. Insulators,** whose general characteristics have already been considered, offer high resistance to the flow of electrons. There are no perfect insulators; all substances will allow currents to pass through them if sufficiently high pressures are applied. Their conductivities are low and their resistances are high. Mica has a specific resistance of about $4 \times 10^{18}$ and insulating rubber $1400 \times 10^{18}$ microhms per cm. cube.

When testing " insulation resistance," say by the Bridge Megger, it is the passage of very minute currents through the insulating substances that causes the instrument to operate.

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* *See* Table V., p. 530.

**47. Quantity of Electricity.**—The unit of quantity of electricity is the coulomb (symbol " Q "). It is approximately equal to $10^{19}$ electrons.

A coulomb (practical unit) = 1/10th of an electro-magnetic unit. (Appendix C).
= $3 \times 10^9$ electro-static units. (Appendix C.)

**48. Current** (symbol " I ") is the measure of the rate of flow of electricity.

**The Ampère is the unit of current,** and it is a rate of flow of 1 coulomb per second.

(Similarly a " knot " is the nautical unit of speed, equal to 1 nautical mile per hour).

If a pressure of 1 volt be impressed on a closed circuit having a resistance of 1 ohm, then a current of 1 ampère will flow through the circuit.

It happens that in practical work we are nearly always interested in the rate of flow of electricity (ampères) and seldom in the amount of electricity that flows (coulombs).

1 ampère $= \frac{1}{10}$ electro-magnetic or absolute unit. (Appendix C.).

For measuring very small currents we use two other units.

The Milliampère (symbol m A) $\frac{1}{1000}$ ampère.

The Microampère (symbol $\mu$ A) $= \frac{1}{10^6}$ ampère.

$$\text{If}\begin{cases} Q = \text{coulombs} \\ I = \text{ampères} \\ t = \text{seconds} \end{cases} \quad \text{then it will be seen that} \quad Q = I \times t \quad \textit{or} \quad I = \frac{Q}{t}.$$

**Example 2.**

If a current of 10 amps. flows for 5 seconds, then the quantity of electricity that passes a point in the circuit will be $Q = I \times t = 10 \times 5 = 50$ coulombs.

A larger unit of **quantity,** used in connection with capacities of accumulators for example, is the **ampère-hour.**

This is equivalent to—

1 coulomb per second for 3,600 seconds, *i.e.*, 3,600 coulombs.

**49. Effects of a Current.**—A current has three different effects—

(1) Heating effect.
(2) Magnetic effect.
(3) Chemical effect.

**The heating effect.**—A wire carrying a current becomes heated. This property is made use of in radiators—electric lamps, valves, &c.

**The magnetic effect.**—A wire carrying a current is surrounded by a magnetic field. This property is of very great importance, and its various effects are dealt with in due course.

**The chemical effect** occurs in electrolytes and finds a practical application to wireless work in connection with primary and secondary batteries.

**50. Electro-motive Force** (E.M.F.).—The term electro-motive force, abbreviated to E.M.F. and sometimes called voltage, electric pressure, or potential difference (P.D.), is used to designate the " push " that moves or tends to move electrons from one place to another—that causes electricity to flow.

The flow of water through a pipe, that is, the number of gallons per second, is determined largely by the difference of hydraulic pressure—in pounds per square inch—between the ends of the pipe. A similar electric pressure or E.M.F. measured in volts causes electricity to flow.

A volt has, when speaking of electricity, somewhat the same meaning as has " a force of one pound per square inch " when speaking of hydraulics.

A greater hydraulic pressure is required to force a given amount of water through a small pipe than through a large one in a given time.

Similarly, a higher voltage is required to force a given amount of electricity through a small conductor than through a large one in a given time.

The distinction between voltage and potential should be clearly understood. The term " potential " is analogous with the hydraulic terms " level " or " head," and the terms " electro-motive force " and " voltage " are analogous with the hydraulic terms " difference-in-level " and " difference of pressure."

It is not correct to say " the potential across the lamp is 110 volts " : instead one should say " the potential difference " (P.D.) or " voltage " across the lamp is 110 volts.

A point is spoken of as being so many volts above or below earth potential.

**51. Electro-motive Force** (E.M.F.) is generated in three different ways :—

(1) By two dissimilar metals or other substances being immersed in electrolytes—such as acids of primary and secondary cells.

(2) By two dissimilar conductors being placed in contact and their junction heated; *cf.* thermal junction of steel and eureka wire used in wavemeters: tellurium-zincite couple used for detecting.

(3) By a conductor being cut in a certain manner by magnetic lines of force : *cf.* dynamo, alternator, transformer, mutual coil, &c.

**52.** The practical unit of electrical pressure is the **Volt.** It is the electro-motive force required to drive a current of one ampère through a resistance of one ohm: or, it is the E.M.F. produced when a conductor is cut by "magnetic lines of force" at the rate of $10^8$ per second.

$$\textbf{1 volt} = 10^8 \text{ electro-magnetic or}$$
$$= \frac{1}{300} \text{ electro-static units. (Appendix C.)}$$

Other units sometimes used are—

The Millivolt (symbol mV) $= \frac{1}{1000}$ volt or a thousandth part of a volt.

The Microvolt (symbol $\mu$V) $= \frac{1}{10^6}$ volt or a millionth part of a volt.

The Kilovolt (symbol kV) = 1000 volts.

**53. Ohm's Law.**—When an E.M.F. exists in a closed circuit it causes a current to flow, the total resistance of the circuit—operating like friction—having to be overcome. It is obvious that the greater the E.M.F. and the smaller the resistance, the greater will be the resulting current; or, the less the E.M.F. and the greater the resistance the smaller will be the current.

This is expressed in "Ohm's Law," which states that "the current is directly proportional to the E.M.F. and inversely proportional to the resistance."

$$\text{or, } I \propto \frac{E}{R} \text{ or Current varies as Voltage} \div \text{Resistance.}$$

From the above relationship, the current cannot be actually calculated, but if the proper units are used, an equation can be formed, thus—

$$\mathbf{I = \frac{E}{R}} \textbf{ or Current equals Voltage} \div \textbf{Resistance.}$$

where Current is measured in ampères,
E.M.F. is measured in volts, and
Resistance is measured in ohms.

This formula only applies to steady conduction currents. The effects of inductance and capacity modify the conditions, and are dealt with later.

**Example 3.**

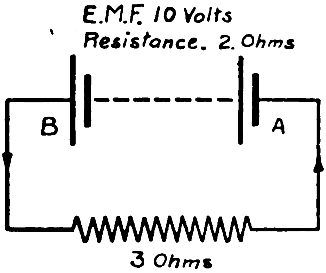


FIG. 5.

Fig. 5 indicates a battery whose internal resistance is 2 ohms, and E.M.F. 10 volts, connected to a resistance of 3 ohms. Find the strength of the current.

$$I = \frac{E}{R} = \frac{10}{2 + 3} = 2 \text{ ampères.}$$

In electro-magnetic units

$$I = \frac{10 \times 10^8}{5 \times 10^9} = \cdot 2 \text{ electro-magnetic unit}$$

$$= 2 \text{ ampères.}$$

The equation $I = \frac{E}{R}$ may also be expressed in the forms $E = IR$ and $R = \frac{E}{I}$.

In the above example, note that if the E.M.F. and resistance remain constant, the current will remain constant, and will have the same value in all parts of the circuit.

This will always be the case as long as there is no division of current but only a single path.

There will be a fall of voltage, however, around the circuit —a " voltage drop " or " IR drop " from point to point.

From B to A a current of 2 ampères flows through a resistance of 3 ohms, so that from B to A there will be a voltage drop of—

$E = IR = 2 \times 3 = 6$ volts. A " voltmeter " connected between A and B would read 6 volts.

This is the terminal P.D. of the battery.

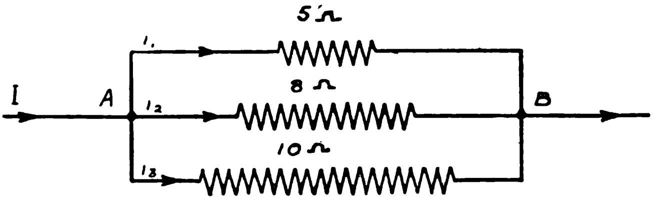
Again, to drive 2 ampères through the resistance of the battery a voltage of $E = IR = 2 \times 2 = 4$ volts is required.

Total voltage to drive current through total resistance $= 6 + 4 = 10$ volts.

Note.—" E " in the formula represents voltage generally—*i.e.*, E.M.F. for the total voltage operating in the circuit, or P.D. or IR drop in a portion of the circuit.

Thus Ohm's Law can be applied to the whole of a circuit or to any portion of it.

**54. Divided Circuits. Resistances in Parallel.**—Kirchoff's first law states that " if a current divides at a point, the sum of the resulting currents is equal in amount to the original current."



*Resistances in Parallel.*

Fig. 6.

**Example 4.**

In the above circuit (Fig. 6) the current arriving at A (I ampères) is equal to the sum of the currents leaving A.

$$I = i_1 + i_2 + i_3$$

Let the P.D. between A and B be E volts : then each of the three branches has a P.D. of E volts across it.

$$\text{Thus : } i_1 = \frac{E}{5},\ i_2 = \frac{E}{8},\ i_3 = \frac{E}{10} \text{ ampères.}$$

Let R ohms be the joint resistance of the three branches.

$$I = i_1 + i_2 + i_3$$

$$\text{hence } \frac{E}{R} = \frac{E}{5} + \frac{E}{8} + \frac{E}{10}$$

$$\text{(Divide by E) } \frac{1}{R} = \frac{1}{5} + \frac{1}{8} + \frac{1}{10} = \frac{17}{40}.$$

$$R = \frac{40}{17} = 2\frac{6}{17} \text{ ohms.}$$

The last three lines show the method of obtaining the total resistance of a number of resistances in parallel.

The total conductivity $\left(\frac{1}{R}\right)$ is equal to the sum of the individual conductivities $\left(\frac{1}{5}, \frac{1}{8}, \frac{1}{10}\right)$: thus the total resistance is obtained.

Again, the currents in the branches are in proportion to the conducting powers or conductivities of the branches.

$$\frac{1}{R} = \frac{1}{5} + \frac{1}{8} + \frac{1}{10} = \frac{8 + 5 + 4}{40} = \frac{17}{40},$$

8 parts, 5 parts, and 4 parts of current in the three branches respectively give a total current of 17 parts.

Hence the conductors will carry $\frac{8}{17}$, $\frac{5}{17}$, and $\frac{4}{17}$ of the total current respectively.

If there are only **two** resistances in parallel (say $r_1$ and $r_2$), we have

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} = \frac{r_2 + r_1}{r_1 \times r_2}$$

$$\text{hence } R = \frac{r_1 \times r_2}{r_2 + r_1} = \frac{\text{their product}}{\text{their sum}}.$$

This is a simple rule for finding their total resistance; but the same rule does not apply to more than two resistances in parallel.

The effect of arranging resistances in parallel is to reduce resistance. The total resistance will be less than that of the smallest of them.

This is obvious, as opening up more paths for the current will make its passage easier, just as opening up a number of gates in a ground containing a crowd of people will make their exit easier.

When a number of similar resistances, like a number of lamps of the same pattern, are joined in parallel, their total resistance is found by dividing the resistance of one by the number in parallel.

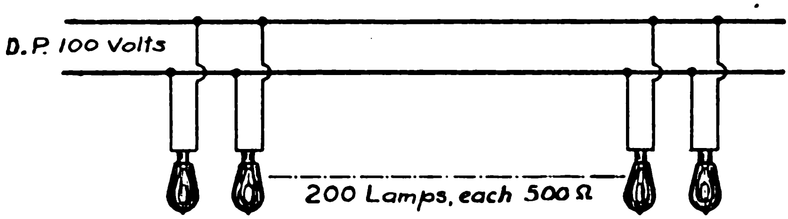


FIG. 7.

**Example 5.**

Let 200 lamps, each of hot resistance 500 Ω, be connected across 100 volt mains, as in Fig. 7.

Then the total resistance of lamps $= \frac{200}{500} = 2 \cdot 5$ ohms.

Total current taken $= \frac{E}{R} = \frac{100}{2 \cdot 5} = 40$ amps.

Current in each lamp $= \frac{40}{200} = \cdot 2$ amp.

or current in each lamp (directly) $= \frac{E}{R} = \frac{100}{500} = \cdot 2$ amp.

Neglecting the IR drop in the mains, each lamp gets the full pressure of the mains. If one is broken or burns out, the rest are not affected.

If two of these lamps were connected in series across the mains, the IR drop in each would be 50 volts, and the current in each $= \frac{100}{500 + 500} = \cdot 1$ amp. (because double the resistance across the mains has to be overcome). We say that, in this case, each is burning at "half brilliancy." If one were to burn out, the other would, of course, cease to burn.

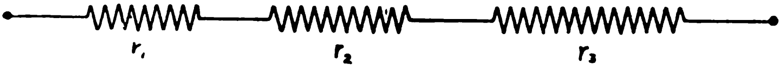


FIG. 8.

**55. Resistances in Series.**—If resistances are joined as in Fig. 8, this arrangement is termed "in series." Then there will be a voltage drop in each resistance, and the current flowing will be accordingly cut down.

The total voltage drop will be:—

$$\begin{aligned}E &= IR_1 + IR_2 + IR_3 \\ &= I(R_1 + R_2 + R_3)\end{aligned}$$

or, given the applied voltage, the current flowing will be

$$I = \frac{E}{R_1 + R_2 + R_3}.$$

That is to say, to find the joint effect of several resistances joined in series, their individual resistances should be added together.

**56. Power.**—(A section on Power and Energy, treated from the mechanical view point, is included in Appendix A, p. 506, and should be studied at this stage.)

Power is the rate of doing work.

If a weight of 55 lbs. is raised through a distance of 10 ft. the work done is 550 ft.-lbs. If this work is done in one second, the rate of working, or the rate at which power is developed, is 550 ft.-lbs. per second.

This is the definition of 1 horse power.

Similarly in an electrical circuit. When an E.M.F. moves a quantity of electricity round a circuit at a certain rate, power is developed.

**The unit of electrical power is the Watt,** which is the power developed when one volt produces a current flow of one coulomb per second (or one ampère).

$$\begin{aligned}\text{Power} &= 1 \text{ volt} \times 1 \text{ coulomb per second} \\ &= 1 \text{ volt} \times 1 \text{ ampère} \\ &= 1 \text{ watt}. \\ \text{Watts} &= \text{Volts} \times \text{Amps}. \\ &= E \times I. \qquad (1)\end{aligned}$$

$$\text{Now } E = I \times R.$$

$$\text{Hence watts} = E \times I = IR \times I = I^2R. \qquad (2)$$

$$\text{Also } I = \frac{E}{R}.$$

$$\text{Hence watts} = E \times \frac{E}{R} = \frac{E^2}{R}. \qquad (3)$$

Here are three expressions for calculating electrical power in watts, of which the first two are in very frequent use.

A larger unit of power is the **Kilowatt** = 1,000 watts.

**57.** It should be clearly understood what is meant by such expressions as a "10 kW. 100 volt" dynamo, or a "40 watt 220 volt" lamp.

The first expression denotes a dynamo which will supply a current of $\frac{10{,}000}{100} = 100$ ampères at 100 volts pressure without being overloaded when rotated at its designed speed.

The second denotes a lamp which requires a current of $\frac{40}{220} = \cdot 18$ amp. at 220 volts to keep it burning at its designed brilliancy.

The idea that $I^2R$ represents heat, energy, or even force, is very prevalent among junior ratings—and others. This is quite wrong. $I^2R$ represents the **rate** at which light and heat energy are produced in the lamp, or the **rate** at which mechanical energy is turned out by the motor, or the rate at which a load is raised.

A cyclist travels at 10 miles per hour. This does not tell us the distance he covers, but simply the rate at which he covers it. To know the distance traversed we must know the length of time for which he rides.

$$\begin{aligned}\text{Distance} &= \text{rate} \times \text{time}\\ &= \frac{10 \text{ miles}}{\text{per hour}} \times 2 \text{ hours (say)}\\ &= 20 \text{ miles.}\end{aligned}$$

Similarly when a certain power is employed for a certain length of time, an amount of energy—in various forms—is available.

58. **Energy,** in the mechanical sense, is the ability of a body to do work by virtue of—

(1) its mass and velocity—Kinetic Energy or

(2) its mass and position—Potential Energy.

Illustrations of each form in electrical work are :—

(1) (*a*) Electricity in motion, as current flowing through a lamp filament for a certain time; heat energy results;

(*b*) mechanical energy produced by a motor running for a certain time;

(2) Electrical energy stored up in charged accumulators or condensers.

The unit of electrical energy is the **Joule** (practical unit) and is the amount of energy produced by or required to produce a power of one watt acting for one second.

or 1 watt = 1 joule per second.

$$\begin{aligned}\text{Energy} &= \text{Power} \times \text{time},\\ &= EI \text{ (or } I^2R\text{) watts} \times t \text{ seconds},\\ &= EIt \text{ or } I^2Rt \text{ joules.}\end{aligned}$$

The absolute unit of energy is **the Erg.**

$$1 \text{ joule} = 10^7 \text{ ergs.}$$

This can be seen from the following :—

$$\begin{aligned}\text{Energy} &= E \times I \times t\\ &= 1 \text{ volt} \times 1 \text{ amp.} \times 1 \text{ sec.} = 1 \text{ joule}\end{aligned}$$

In e.m. units, $= 10^8 \times \frac{1}{10} \times 1 = 10^7$ ergs.

Still larger units than the joule are the **watt-hour** and the **kilowatt-hour**; the latter is known as the Board of Trade **(B.O.T.) unit.**

$$1 \text{ watt-hour} = 1 \text{ watt} \times 1 \text{ hour}$$
$$= 1 \frac{\text{joule}}{\text{sec.}} \times 3{,}600 \text{ secs.}$$
$$= 3{,}600 \text{ joules.}$$
$$1 \text{ kW.-hour} = 3{,}600{,}000 \text{ joules.}$$

**Example 6.**

A 100-volt lamp of 500 ohms' hot resistance is connected across 100-volt mains. Find the energy taken from the mains in one minute and the heat developed by the lamp.

$$\text{Energy} = \text{power} \times \text{time.}$$
$$= \frac{E^2}{R} \text{ joules per sec.} \times 60 \text{ secs.}$$
$$= \frac{100^2}{500} \times 60 = 1{,}200 \text{ joules.}$$
$$\text{or } I = \frac{100}{500} = \cdot 2 \text{ amp.}$$

$$\text{Energy} = EIt = 100 \times \cdot 2 \times 60 = 1{,}200 \text{ joules,}$$
$$\text{or Energy} = I^2Rt = \cdot 2^2 \times 500 \times 60 = 1{,}200 \text{ joules.}$$

This amount of energy is converted into heat. The unit of heat is the "**calorie,**" and

$$1 \text{ calorie} = 4 \cdot 2 \text{ joules.}$$

$$\text{Thus, } 1{,}200 \text{ joules} = \frac{1{,}200}{4 \cdot 2} = 286 \text{ calories.}$$

**Example 7.**

Ten accumulators, each having an E.M.F. of 2 volts and a resistance of ·05 ohm, are to be charged with a current of 8 amps.

Find the amount of energy stored in them in 15 minutes (assuming that their E.M.F.'s remain at 2 volts) and the amount of heat energy wasted.

E.M.F. of battery opposing pressure applied = 20 volts.

Resistance of battery = $\cdot 05 \times 10 = \cdot 5$ ohm.

Voltage to drive 8 amps. through battery resistance = $8 \times \cdot 5 = 4$ volts.

Voltage to overcome back pressure of battery = 20 volts.

Hence required charging voltage = 24 volts.

Energy stored up in 15 minutes in the form of electrical energy

$$= E \times I \times t$$
$$= 20 \times 8 \times (15 \times 60) = 144{,}000 \text{ joules,}$$
$$\text{or, } 20 \times 8 \text{ watts} \times \tfrac{1}{4} \text{ hour} = 40 \text{ watt-hours.}$$

$$\text{Heat energy} = E \times I \times t$$
$$= 4 \times 8 \times \tfrac{1}{4} = 8 \text{ watt-hours.}$$
$$\text{Or, } = 4 \times 8 \times 15 \times 60 \text{ joules} = 28{,}800 \text{ joules}$$
$$= \frac{28{,}800}{4 \cdot 2} = 6{,}860 \text{ calories.}$$

## LAMPS.

**59.** Incandescent lamps are rated by their voltage, power, and candle power. There are three types in common use—carbon filament, metallic filament and "gas-filled." The two latter are of more modern introduction, and though perhaps more costly, are more efficient (as regards consumption of electrical energy) and do not blacken as do carbon lamps, due to deposition of carbon.

Each type is referred to as consuming so many "watts per candle power." Carbon lamps take, roughly, 3·5 to 4 watts per c.p., whereas metallic filament lamps vary, roughly, from 1 to 2 watts per c.p., and gas-filled lamps take ½ watt per c.p. The two latter consume less power to give the same amount of light, and hence are more efficient.

**Example 8.**

A 220-volt 32-c.p. metallic filament lamp of efficiency 1·7 watts per c.p. is burned from 220-volt mains; find what current it takes.

$$\text{Watts supplied} = 32 \times 1{\cdot}7 = 54{\cdot}4 = \text{EI}.$$

$$\text{I} = \frac{\text{EI}}{\text{E}} = \frac{54{\cdot}4}{220} = {\cdot}247 \text{ amps.}$$

For general lighting purposes metallic filament lamps are preferable, but for accumulator charging on a small scale, where lamps in parallel are used to regulate the charging current, carbon lamps are preferable, as they pass more current, and fewer are required.

## PRIMARY CELLS, OR BATTERIES.

**60.** The existence of an electric current in any circuit means that energy in some form is being liberated at the generating source; and the continuance of this current necessitates the continuous expenditure of energy. In the case where the current is supplied by a dynamo driven by a steam or gas engine, the source of the supply is the coal, and the place where the energy is being liberated is the furnace. Coal contains a large supply of energy, which it readily liberates in the form of heat, and which, after several transformations, may appear in a circuit in the form of electrical energy, and is there used for lighting, running motors, energising W/T sets, &c.

The coal becomes oxidised or burnt up in the process, and the quantity of energy that can thus be obtained is clearly limited by the amount of coal consumed or burnt.

In the case of an ordinary voltaic cell the conversion of the energy of supply into electrical energy is a much simpler and less wasteful process, but the material which acts as the source of supply—in other words the fuel—is far more expensive.

In most cells the fuel consists of zinc and acid, which are consumed, but which, instead of giving out their energy in the form of heat, give it out directly in the form of current.

A cell is in reality nothing more than a little furnace in which zinc instead of coal is used as fuel, and in which the "burning" is not simple oxidisation.

**61.** Primary cells consist of three essential constituents for the production of E.M.F., viz., a positive plate, a negative plate, and an exciting liquid (termed the "electrolyte").

According to the nature of the plates and the liquid, a certain P.D. is set up between the plates. When the cell is on closed circuit, *i.e.*, when the plates are connected through an outside circuit, and a current flows, chemical energy stored up in the cell is converted into electrical energy.

The general action of any type of primary cell may be briefly summarised as follows:—

The negative plate—generally zinc—dissolves gradually in the electrolyte, liberating hydrogen.

The positive plate—copper, carbon, or platinum—remains unaffected, and a film of hydrogen gas accumulates over it; this process is called "polarisation." To prevent polarisation (which increases the resistance of the cell, and sets up a counter E.M.F.) a fourth substance—termed a "depolariser"—is introduced in the cell to absorb the hydrogen.

The conventional way of considering the direction of the flow of the electric current is from the positive to the negative terminal. As we have seen before, however, the current really consists of an electron flow from the negative to the positive terminal.

Thus the negative plate provides a supply of electrons, which flow from it through the outside circuit to the positive plate, and back through the cell to the negative plate. They are set in motion by the chemical action of the cell.

The E.M.F., or P.D. between the terminals, on open circuit depends entirely on the substances used for the positive plate, negative plate, and electrolyte and not on the size of the cell.

A diluted solution of sulphuric acid in water or a saturated solution of sal-ammoniac are commonly used as electrolytes.

The resistance of the cell depends upon the area of the plates immersed, their distance apart, and the specific resistance of the liquid. The larger the plates and the closer they are together, the less is the internal resistance.

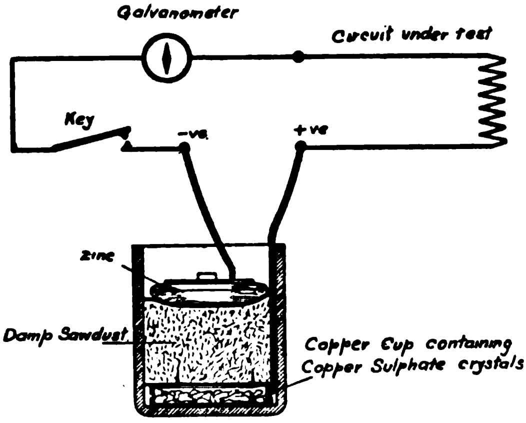
The advantage of a large cell is not in the value of its E.M.F., but in its smaller resistance, owing to the area of surface contact; also, it contains more energy (stored in the chemicals) and therefore lasts longer.

**62.** The Daniell and Menotti-Daniell cells consist of copper, zinc, dilute sulphuric acid, and copper sulphate solution (depolariser). Their E.M.F.'s are 1·1 volts each. Their resistances depend on their size. They give a steady current when in service.

The Leclanché cell consists of carbon, zinc, sal-ammoniac solution, and manganese peroxide (depolariser). E.M.F. 1·5 volts. Resistance varies with size.

When in service the current quickly falls, and so these cells are chiefly used for intermittent work such as bells.

Nearly all dry cells are of this type, the sal-ammoniac being contained in a paste or jelly.



Menotti-Daniel Cell.
*Test Battery.*
FIG. 9.

The Menotti test battery, Fig. 9, consists of a Menotti-Daniell cell (1 volt and 30 ohm resistance approx.), a key, and a 20-ohm galvanometer. The circuit under test is connected between the other terminal of the galvanometer and the positive battery terminal.

In wireless work it is chiefly used for testing for "conductivity." When the key is pressed and a swing of the galvanometer needle is obtained, the circuit is continuous or unbroken. Its high resistance is necessary in testing detonator or gun circuits, *i.e.*, so that the current will be small and there will be no risk of firing.

**63.** As a typical example of the action of a primary cell, the action of a Menotti is here described.

The Menotti consists of a copper cup containing copper sulphate crystals (positive plate), a zinc slab (negative plate) and damp sawdust.

The zinc (Zn)* is attacked by the water ($H_2O$) in the sawdust, and ZnO is formed: $H_2$ is released.

---

* The letters Zn, $H_2SO_4$, &c., denote the nature of the atoms that go to make up a molecule of the substance; thus, a molecule of sulphuric acid contains two atoms of hydrogen ($H_2$), one atom of sulphur (S), and four atoms of oxygen ($O_4$).

This passes through to the copper sulphate ($CuSO_4$), sulphuric acid ($H_2SO_4$) is formed, and copper ($Cu$) deposited.

The $ZnO$ would normally stick to and insulate the zinc plate, being insoluble in water, but the sulphuric acid creeps up and dissolves it.

Thus we have zinc and copper plates, and a dilute sulphuric acid solution.

Now dilute sulphuric acid has the property of breaking up into ions.

Each molecule of the acid ($H_2SO_4$) breaks up into positive ions H and negative ions $SO_4$. Furthermore, the zinc plate when submerged in the acid solution which acts upon it, tends at its surface to break up into positive zinc ions and electrons. The positive zinc ion is attracted to and combines with the negative ions $SO_4$ to form neutral zinc sulphate $ZnSO_4$.

The free electrons are driven up from the zinc plate by the repulsion from below, and move round the external conducting circuit to the copper plate: but note also, that the positive hydrogen ions H, which are liberated in the electrolyte, are attracted to the copper plate. Here each positive ion combines with an electron, which has come round from the zinc, to form a neutral atom of hydrogen.

Thus in the cell there is a movement of positive hydrogen ions towards the copper plate, and also a movement of negative $SO_4$ ions towards the zinc plate, while in the external circuit there is an electron current only.

**64. Cells in Series and Parallel.**—When cells **are arranged in series,** the total E.M.F. is the sum of their separate E.M.F.'s, and the total resistance is the sum of their separate resistances.

When they are **connected in parallel** (all positives to one terminal and all negatives to another) their total E.M.F. is that of one cell, and their total resistances that of one cell divided by the number of cells (assuming each to have the same E.M.F. and resistance).

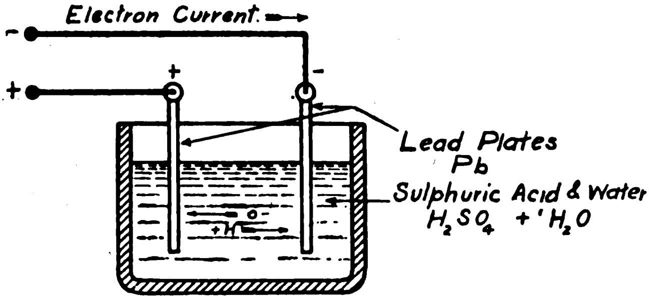
## SECONDARY BATTERIES, ACCUMULATORS OR CELLS.

**65.** A Secondary Battery, or Accumulator, is an arrangement from which an electric current may be drawn for a certain time, like a primary battery; unlike the primary battery, however, when it is exhausted it may be recharged by having an electric current passed through it.

An accumulator does not store electricity; it stores energy.

When it is being charged the electrical energy imparted to it is transformed into chemical energy, which is stored in the cell. Then when the cell discharges, that is, when an external circuit is completed through which current can be forced by the E.M.F. of the cell, the stored energy is reconverted into electrical energy.

66. A **primitive form** of accumulator would be two lead plates (Pb) immersed in sulphuric acid ($H_2SO_4$) diluted with water ($H_2O$), as in Fig. 10.



*Primitive Form of Accumulator.*

Fig. 10.

67. **Charging the Accumulator.**—Suppose a source of direct current is joined up to the two lead plates, as in Fig. 10.

The electrode connected to the positive main is termed the Positive Electrode.

The one connected to the negative main is called the Negative Electrode.

The action in charging the accumulators may be summarised as follows: it is actually more complicated.

Some of the molecules of the acid and of the water are "ionised," *i.e.*, broken up into positive and negative ions of equal, but opposite charges, thus:—

$$(H_2{}^{+ve}\ SO_4{}^{-ve}) \qquad (H_2{}^{+ve}\ O^{-ve})$$

These form the carriers for the current through the electrolyte. When the cell is connected to the source of power—*e.g.*, the mains—as above, the positive Hydrogen ions are attracted to the Cathode, and the negative Oxygen ions to the Anode.

**Each positive hydrogen ion** on reaching the negative terminal joins with an electron (supplied by the mains) and a neutral atom results.

Two atoms combine to form a neutral molecule of hydrogen gas ($H_2$).

The lead and hydrogen do not combine chemically but the surface of the lead becomes smoother and covered with pure "spongy lead" of light slate colour.

**Each negative oxygen ion** at the positive terminal joins with a positive lead (Pb) ion (*i.e.*, a lead atom less an electron) and a neutral molecule of "Lead Monoxide" (PbO) or "Litharge" is formed which is deposited on the positive terminal.

As more oxygen arrives at the anode the lead monoxide becomes Lead Peroxide (PbO + O), chocolate brown in colour.

This is the final stage. No more oxygen combines with the lead after a coating of brown lead peroxide covers the whole surface. The oxygen then rises to the surface and the plate "gases" freely.

Thus the charged accumulator consists of :—

Positive plate: lead peroxide coating; chocolate brown colour.
Negative plate: spongy lead coating; light slate colour.
Electrolyte: sulphuric acid and water, a little stronger than originally, as some molecules of water have been removed.

A difference of pressure will now exist between the plates of about 2·2 volts. If disconnected from the mains and allowed to discharge through an external circuit, a current will flow from the positive to the negative terminal, but only for a short time, as the plates of such an accumulator as that described have only a small "holding power" or "capacity" due to the small amount of "active material" on them.

The P.D. would quickly fall to zero.

**68. Construction of Accumulators.**—In practice the holding power or capacity is increased by furrowing, grooving, gimping or otherwise increasing the working surface of the lead plates, and the prepared surface is filled with the active material—lead peroxide, or spongy lead.

The greater the number of plates in a cell and the larger their surface, the greater will be the capacity and current output.

The positive and negative plates are arranged alternately, each group being connected at the top by lugs to a lead bar.

The negative group contains one plate more than the positive group, except in two-plate cells.

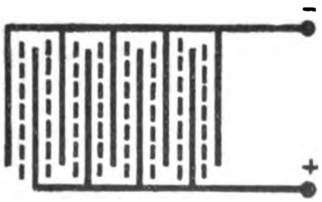


Fig. 11.

The plates are placed close together to ensure low resistance, and are kept apart by separators of wood, glass, celluloid, &c. (as indicated in Fig. 11.)

**69. The Electrolyte.**—The sulphuric acid and water must be free from impurities. If distilled water is not available, rain water or melted artificial ice is recommended.

Sulphuric acid when concentrated has a specific gravity of about 1·84, *i.e.*, it is 1·84 times as heavy as an equal bulk of water.

When the cell is charged the acid strength should be about 1·22 (or, as sometimes written, 1220). Slightly different strengths are stated by different makers.

This strength gives approximately the least specific resistance. A stronger acid, in addition to having a higher specific resistance, attacks the plates to an undesirable degree.

To "break down" the acid, it is mixed with about four times its bulk of water, and care must be exercised in the mixing.

When mixed with water a great amount of heat is developed. The acid should be added gradually to the water, stirred meanwhile, and not used till cool.

On no account must water be added to acid.

The strength or "specific gravity" is tested by a "hydrometer"—an instrument with a weighted bulb and a thin graduated stem; when in the acid, the reading is taken at the point on its scale at the surface.

As will be explained shortly, the acid becomes weaker as the cell is discharged, and will fall to about 1170 at about 1·85 volts—the point at which discharging should be stopped.

Its strength is recovered on recharging.

**70. Initial Charge.**—The makers issue directions which must be carefully followed if the battery is to be maintained in a state of efficiency.

The general plan is to give a prolonged first charge immediately after the acid has been poured in.

The acid will fall in specific gravity as soon as it is poured into the cells and will continue to do so for the first 12 or 18 hours.

During charge it will gradually rise, and the charge should not be considered complete until the voltage and specific gravity show no rise over a period of, say, five hours, and gas is being given off freely from all plates.

At the end of the charge the voltage will have risen to 2·5–2·7 volts per cell.

After the charging current is cut off, the voltage per cell will immediately fall to about 2·2 volts, or slightly lower, at which it will remain while the battery is left on open circuit.

The battery should not be left unworked for more than a week without recharging.

With large cells, in which a hydrometer can be inserted, the specific gravity of the acid is the most reliable guide. With small cells, the acid should be tested occasionally, by transferring some acid with a syringe to a narrow tube and using the hydrometer in the latter.

## Tests for Completion of Charge.

(1) Appearance of plates: positive—chocolate brown.
negative—slate grey.
and no trace of whiteness on either.
(2) Voltage: 2·5 to 2·7 volts.
(3) Plates gassing freely.
(4) Specific gravity of acid: about 1220, according to maker.

In the first week, the cell should be given plenty of work, and an hour's extra charging on the first few charges.

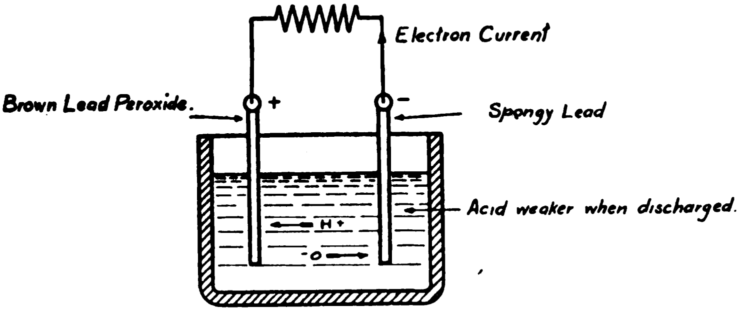


FIG. 12.

**71. Discharging.**—The discharge current flows in the opposite direction to the charging current. Oxygen ions flow to the negative plate and hydrogen ions to the positive plate.

**At the positive plate** the hydrogen reduces the peroxide to monoxide, *i.e.*,

$$PbO_2 + H_2 = H_2O + PbO,$$

then the acid readily attacks the monoxide and lead sulphate (white) is formed on the plate :—

$$PbO + H_2SO_4 = H_2O + PbSO_4 \text{ (lead sulphate).}$$

Thus the peroxide is gradually removed and the plate becomes partly coated with white lead sulphate.

**At the negative plate,** the oxygen ions form, with the lead, lead monoxide (PbO) and the acid converts the latter, as above, into white lead sulphate. Thus the negative plate also becomes partly coated with lead sulphate.

NOTE.—In these two sets of actions, some acid is used up and water is produced, causing the specific gravity of the acid to fall.

The voltage should not be allowed to fall below about 1·85 volts.

The specific gravity will be about 1170 at this stage. If the discharge is carried persistently beyond this point more sulphate will form on each plate, and when each plate is totally covered the voltage will be zero.

*Caution.*—A cell must not be left for any length of time in a discharged state.

**72. Recharge.**—The process consists of removing the sulphate from each plate.

**At the positive plate** (*see* Fig. 10) oxygen ions arrive and combine with the lead of the lead sulphate to form the brown peroxide; the $SO_4$ being restored as acid to the electrolyte.

$$PbSO_4 + O + H_2O = PbO_2 + H_2SO_4.$$

**At the negative plate,** hydrogen ions arrive, remove the $SO_4$ to form acid, and spongy lead remains, *i.e.*,

$$PbSO_4 + H_2 = Pb + H_2SO_4.$$

NOTE.—By the action at each plate, acid is restored to the electrolyte, thus raising the specific gravity in the recharging process.

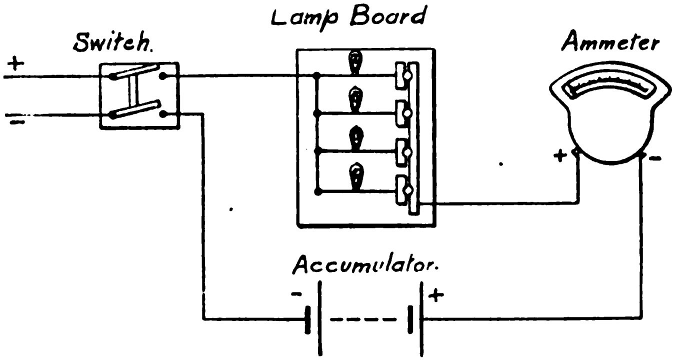
When the sulphate has been entirely removed from the plates, the hydrogen and oxygen gases have no more work to do, and they rise in bubbles to the surface and escape. That is, the cell "gases" freely. This is allowed to continue for a reasonable time, *i.e.*, until the acid reaches a maximum strength and the voltage reaches 2·5–2·7 volts.

When the cell is fully charged, and lying idle, the plates are less liable to be attacked by the acid.

The charge in ampère-hours should generally be about 10 per cent. more than the discharge in ampère-hours.

**73. Method of charging.**—As has been explained, the positive plate is connected to the positive main, and the negative plate to the negative main. Passing current through the cells in the wrong direction will ruin it.

To determine which is the positive terminal, connect an ammeter in the circuit, as in Fig. 13.



*Accumulator on charge.*

FIG. 13.

The ammeter terminals are always marked "+" and "—." If the pointer swings in the correct direction over the scale, the lead connected to the "+" of the ammeter will be that from the positive main.

According to the size of the cell a certain charging rate or current is necessary; this is stated by the maker. We will consider how the particular value of the charging current is obtained.

**Example 9.**

Suppose two small accumulators, each of E.M.F. 1·9 volts and resistance ·1 ohm, are to be charged by a current of 4 amps. from 220 volt mains through leads of resistance ·1 ohm.

If they were connected directly across the mains an enormous current would flow.

The pressure of the mains has to overcome the back pressure of the cells in series (3·8 volts) and the resistance of the cells and leads (·3 ohms altogether). Thus $220 - 3{\cdot}8 = 216{\cdot}2$ volts are available to drive current through ·3 ohm.

$$\text{Current} = \frac{216{\cdot}2}{{\cdot}3} = 721 \text{ ampères,}$$

which would burn up the cell.

In order that just the right amount of current shall flow, some form of resistance must be included in the circuit.

The most convenient form for small charging currents is a "lamp resistance," consisting of lamps, of the voltage of the mains arranged in parallel (Fig. 13).

The more lamps in parallel the greater will be the current that will flow through the circuit, but naturally we wish to use as few lamps as possible, so that we choose high c.p. carbon lamps.

Suppose that the 220 volt lamps available for our use are two 50 c.p., and a number of 16 c.p. carbon lamps.

$$\text{50 c.p. (4 watts per c.p.) take 200 watts}: \ I = \frac{200}{220} = {\cdot}9 \text{ A.}$$

$$\text{16 c.p. (4 watts per c.p.) take 64 watts}: \ I = \frac{64}{220} = {\cdot}3 \text{ A.}$$

Thus two 50 c.p. (1·8 amp.) and seven 16 c.p. (2·1 amp.) lamps in parallel would allow a current of $1{\cdot}8 + 2{\cdot}1 = 3{\cdot}9$ amps. to flow.

If a number of 50 c.p. lamps were available, four of these (3·6 amp.) and one 16 c.p. (·3 amp.) would give 3·9 ampères. This would be preferable, as fewer lamps are required.

When only a few cells in series are being charged, their back pressure is negligible in comparison with the pressure of the mains.

The lamps in the circuit are taking practically their "full brilliancy" current.

High potential batteries (50 volts or 100 volts) have naturally a greater back pressure, and the lamps used do not get the full pressure of the mains.

For example, a 150 volt battery used in a valve receiving set requires, for charging, a 2½ c.p. 220 volt carbon lamp in series.

Normally this lamp would take about ·05 amp., but in this case the pressure applied would only be about 220 — 150 = 70 volts, and the lamp would not take as much as ·05 amp., and would not burn at full brilliancy.

**74. Sediment.**—In time, the active material on the plates gradually disintegrates and a sediment forms at the bottom of the cell. Care must be taken that this does not reach the bottom of the plates to cause short-circuiting. Too much sediment may be produced by charging too much or at too high a rate. Its colour indicates whether the cell is receiving normal treatment; if so, the sediment should be brown.

**75. Sulphating.**—In the discharge action, described above, we saw that the lead sulphate forms on the plates in the ordinary discharging process.

This is not what is known as "sulphating." The latter is due to incorrect treatment—such as, cell not charged sufficiently especially if new, over discharge, acid too strong, and a discharged cell unattended to.

A coating of hard white lead sulphate forms on the plates, and this is difficult to remove.

The plates in consequence become light in colour and lose their porosity and holding power.

"Buckling" of the plates is also very liable to occur.

The simplest remedy, if the sulphating is not too deep-seated, is prolonged and repeated charging at low rate, say at half-normal charging current, and when full gassing occurs, at quarter-normal.

**76. Change of Acid Strength.**—The water in the electrolyte gradually evaporates and must be replaced at intervals to the proper level. The solution should be stirred to prevent the water lying on top, or, in small enclosed cells, the water should be introduced well below the surface by a syringe. This is best performed just before the charge and the gassing will ensure thorough mixing.

Acid may be lost by over vigorous gassing; thus a check must be kept on the electrolyte. It is very inadvisable to add strong acid to a cell to bring up the specific gravity. A better plan is to refill the cell with fresh acid of correct specific gravity.

**77. Capacity and Efficiency.**—The "capacity," or holding power, is rated in "ampère-hours," and in "watt-hours." Service cells are usually rated on their output over a period of five hours.

The output at other rates will be greater or less than the standard rate according as the time of discharge is more or less than five hours: *e.g.*, a 100-Ah cell discharged in one hour would only give about 60 amps., but if discharged in ten hours would give 12 amps.

The efficiency denotes the ratio of the capacity output to the input. The " ampère-hour " efficiency is from 80–90, and the " watt-hour " efficiency from 60–75.

Thus, if a cell is charged at 10 amps. for 16 hours, the input is 160 amp.-hours.

The output would be about $160 \times \frac{80}{100} = 128$ amp.-hours, which would give, say, a discharge current of 9 amps. for about 14 hours, and an efficiency of $\frac{128}{160} \times 100 = 80$ per cent.

**78. Precautions.**—

Give battery proper initial charge.

Give a new battery plenty of work and liberal charging.

Do not charge too much or too little, or at too high or too low a rate.

Do not run batteries too low in voltage or specific gravity.

Do not allow batteries to stand long completely discharged.

Charge once a week if possible.

Sediment should not reach bottom edges of plates.

Keep plates covered with electrolyte, making up evaporation losses with distilled water.

Test strength of acid periodically.

Keep terminals and top of cell clean and dry, and terminals coated with vaseline.

## ELECTRIC AND MAGNETIC FIELDS.

**79. Electric Field.**—It has already been stated, in para. **35,** that like charges repel one another and unlike charges attract one another.

Thus, one electric body can influence another one at a distance.

We explain this by saying that any electrified body, such as an electron or an ion, extends from itself a number of " tubes of force," which may be represented as in Fig. 14.

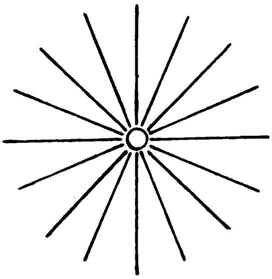
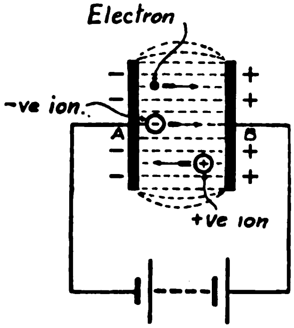


FIG. 14.

These " tubes of force " are all conventionally supposed to terminate on another charge of opposite sign, as for instance, a positive ion in some neighbouring conductor.

The space occupied by these tubes or lines of force is termed an electric field. These lines represent the direction in which the charged body attracts other charged bodies of unlike sign, and repels bodies of like sign.

**80.** Again, suppose two copper plates, A and B, are joined up as in Fig. 15, to a battery, plate A will have a surplus of electrons, *i.e.*, a negative charge, and plate B a deficit of electrons, *i.e.* a positive charge.



*Electric Field between the Charged Conductors.*
FIG. 15.

There will be an electric field between the plates, as indicated by the dotted lines.

If a free electron, or a negative ion, be introduced between the plates, it will be attracted towards the positive plate, and repelled from the negative plate.

A free positive ion will be repelled by the positive plate and attracted by the negative plate.

If the material intervening between the plates is an **insulator,** or "**dielectric,**" the electrons in it will **not** be free, but the positive and negative charges in each atom will be **strained** towards the negative and positive plates respectively, and the dielectric is said to be in a **state of strain.** By the peculiar nature of insulating substances, the electrons in them are firmly locked up in their atoms, and cannot move out of them except by a very high electrical pressure, but will only be strained in one direction under the influence of an electric field.

## Electric Field Density.

**81.** The E.M.F. between these plates is equivalent to a field acting at every point of the dielectric. This is called the **electric field density,** and is defined as the force per unit charge of electricity.

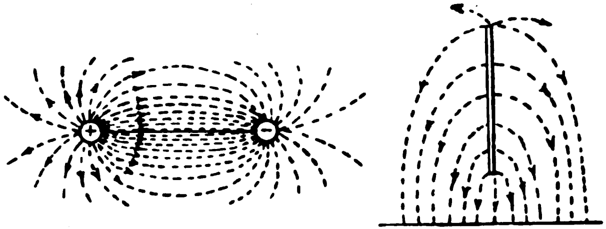
The value of the electric field density at any point between the plates is the ratio of the E.M.F. between the plates to the distance between them.

Electric field density D is thus given by

$$D = \frac{E}{d}.$$

where E is the E.M.F. between two points in the dielectric, a distance d cms. apart. "D" is commonly expressed in volts per centimetre. It is a quantity of importance in connection with electric waves.

The electric field shown in Fig. 15 is the same everywhere in direction and value. This is called a uniform field. There are many other kinds of fields. The electric fields about two small unlike charges is shown in Fig. 16 (*a*).



*Electric field between two oppositely charged bodies.*
*a*

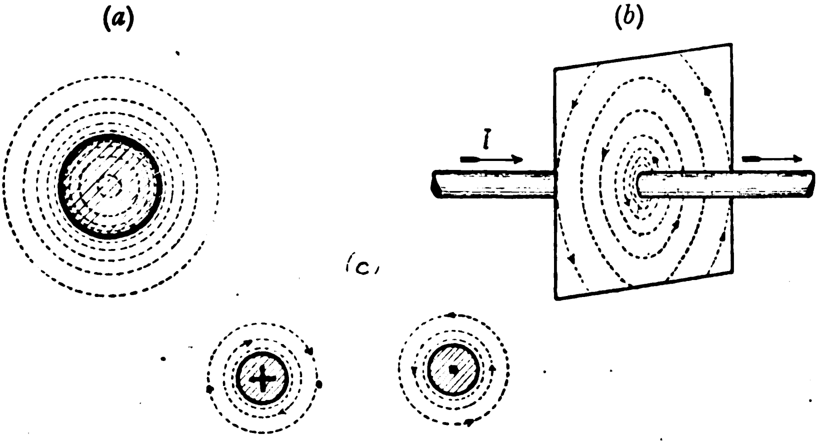
*Electric field about a charged vertical wire.*
*b*

FIG. 16.

Another example is given by two bodies, one of which is a long vertical wire and the other is a conductor extended in a horizontal direction. The field about the system will be as represented in Fig. 16 (*b*). This represents the form of field in the case of the wireless aerial.

**82. Magnetic Field.**—When an electron current is flowing through a conductor, under the influence of an applied E.M.F., the electric fields due to each electron set up a sort of "swirl" in the æther, just as when a ship is moving through the water with her propeller stopped, a swirl is set up in the water.

This "swirl" is termed a magnetic field.



*Magnetic Field round a Conductor carrying a Current.*

FIG. 17.

A single conductor carrying a current thus has a magnetic field surrounding it. The motion or flow of the electrons sets up a magnetic strain in the æther. The magnetic lines of force are in the form of concentric circles, both inside and outside the conductor, as illustrated in Fig. 17 (*a*) and (*b*).

Fig. 17 (*c*) illustrates how the direction of the magnetic swirl depends on the electric current.

The left hand figure illustrates a current flowing away from the reader, in which case the positive direction of the lines of force is in a counterclockwise direction.

The right hand figure illustrates a current flowing towards the reader, in which case the positive direction of the lines of force is in a counterclockwise direction.

The whole of the magnetic field is filled with lines of force, and there is a magnetic force at any point in the field. The difference in the distance apart at which the lines are drawn indicates the difference in the strength of the magnetic force at various points.

In this case the strength is greatest at or near the surface of the conductor both within and without.

" The " positive " direction of the lines of force, as indicated by the arrow, Fig. 17 (*b*), may be determined by " Maxwell's Corkscrew Rule " :—" Imagine a right-handed screw to be along the wire and to be twisted so as to move in the direction of the current; the direction in which the thumb rotates is the positive direction of the lines of force."

There are other rules, but we will adhere to this one, probably the most frequently used in the Service.

**83. The Helix or Solenoid.**—If two wires carrying currents are placed parallel to one another the resultant magnetic field will be as indicated in Fig. 18 (*a*), if the currents in the two wires are in opposite directions, or, as indicated in Fig. 18 (*b*), if they are in the same direction.

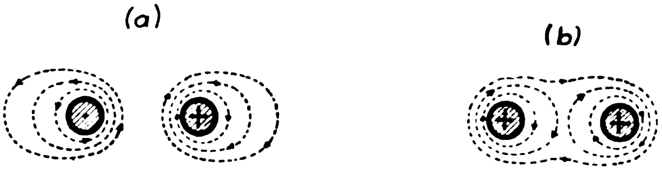
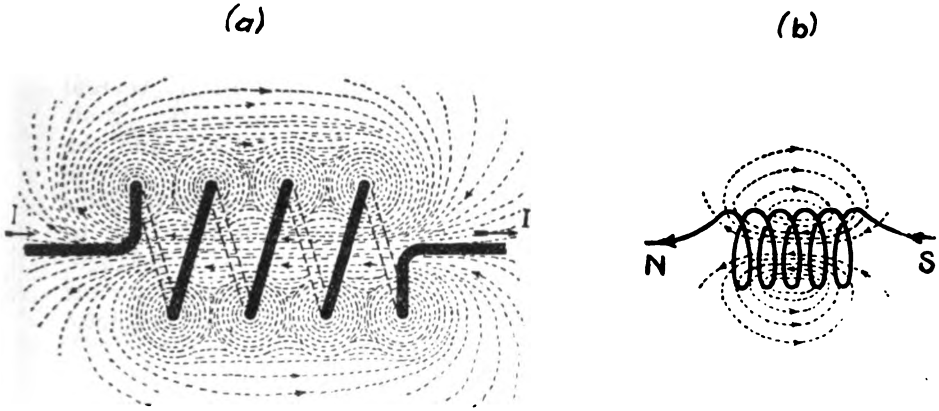


FIG. 18.

A Solenoid—Helix—or coil of wire—carrying a current has a magnetic field as indicated in Fig. 19 (*a*) and (*b*).

Lines of force are produced in a lengthwise direction through the coil, emerging at the ends, and completing the magnetic circuits through the surrounding medium. It can be seen from the diagram how the concentric lines of force merge together to give the resulting field.



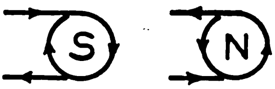
*Field round Solenoid.*

FIG. 19.

The end of the coil from which the lines of force come out is termed its **North Pole,** and the end at which they enter is termed its **South Pole.**

The "End Rule" or "Clock Rule" for determining the polarity of a coil is:—"Look at one end of the coil; if the current flows in a clockwise direction (either towards or away from you) then that end will have south polarity; if anticlockwise, north polarity."

This is illustrated in Fig. 20.



*Illustrating "Clock Rule."*

FIG. 20.

**84. Flux Density.—The strength of the magnetic field** will depend upon the **current strength** and the **number of turns,** *i.e.*, upon the number of "ampère-turns." As the number of turns in a given coil is fixed, the flux will be proportional to the current.

By "**Flux**" we mean the total number of lines of force through the coil, and it is usually denoted by the letter Φ ("capital phi").

**The "flux" density is the number of lines per square centimetre** in any part of a cross section of the magnetic field, and is denoted by "**H**" **lines per square centimetre** if air or any non-magnetic substance fills the magnetic field.

The more closely the turns are wound together, the more concentrated will be the magnetic field at each end of the coil.

**85.** If **iron** is placed within a helix, the magnetic properties of the helix are then very much more pronounced. This is because iron is the best conductor of magnetic lines of force that is known; it is a better conductor than air by several hundred times. The presence of iron in a magnetic circuit decreases the opposition to the flow of lines of force, and the number of lines is thereby very greatly increased. Where a helix has no iron core, some of the lines leak out of its sides between the turns and do not extend through it from end to end. Not only does the iron decrease this magnetic leakage but it also increases the number of lines in the magnetic circuit as above noted, because iron is a better conductor of magnetic lines of force than is air.

This is indicated diagrammatically in Fig. 21.

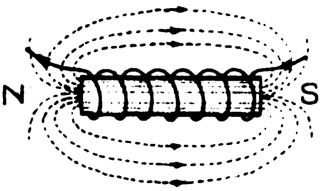
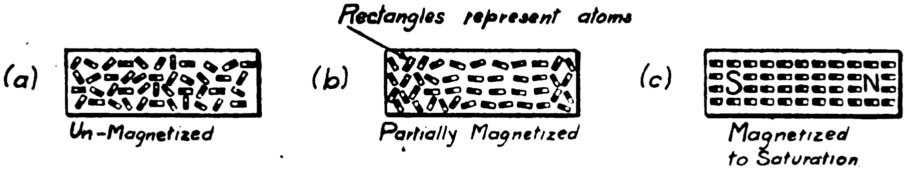


Fig. 21.

**86. Magnets.**—Each atom in a bar of iron is itself a small magnet, because the electrons revolving about the nucleus of an atom create a magnetic field through or in the atom—in much the same way as an electric current circulating round through the turns of a coil of wire, creates a magnetic field through the coil.

In substances which exhibit no external evidence of magnetisation, the atoms lie "anyhow," so that the minute magnetic field due to any one of them is neutralised by the field of some other one, which is in such a position that their fields oppose and annul one another. (Fig. 22 (*a*).)

In magnetic substances, such as iron or steel, the atoms are capable of being "lined up," when the substance is under the influence of a magnetic field, so that their fields will all be in the same direction, and thus act in unison.



*Illustrating Magnetisation of Metals.*

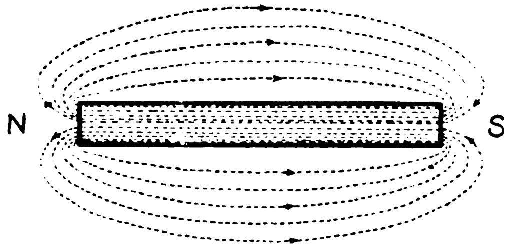
Fig. 22.

Thus, Fig. 22 (*b*) represents diagrammatically a bar of iron which is under the influence of a weak magnetic field, and is partially magnetised. Fig. 22 (*c*) represents the iron under the influence of a strong magnetic field, and is fully magnetised, or "saturated." All of the north poles of the atoms point towards the north pole of the body, and their south poles point towards the south pole of the body.

**87. Iron and Steel.**—Soft or well-annealed iron (made by raising the iron to a red heat and cooling gradually) is very permeable and a multiplying effect of 3,000 times is common.

Although iron will readily become strongly magnetised, it just as readily loses its magnetic properties when the magnetising force is removed, *i.e.*, it has low "retentivity."

Yet, there will generally be a certain amount of residual magnetism as illustrated in Fig. 23, and in connection with this the term "hysteresis"—meaning "lagging behind"—is used. **Hysteresis** is the disinclination of a magnetic substance to become magnetised or demagnetised immediately the magnetising or demagnetising forces are applied—*i.e.*, the effect does not keep in step with the cause.



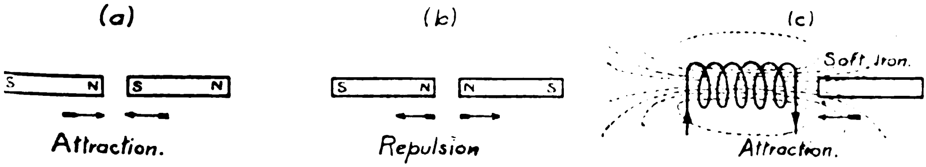
*Permanent Magnet.*

FIG. 23.

**Steel,** on the other hand, is not nearly so permeable as iron, but it is much more retentive, hence its suitability for permanent magnets.

Soft iron is adopted for electro-magnets, and in machines and instruments such as dynamos, motors, transformers, impedance coils—in which the iron has to undergo cycles of magnetisation—it is extensively used.

**88. Laws of Magnetic Attraction and Repulsion:**—(1) **Unlike poles attract.** Thus if two magnetised pieces of steel are placed with their respective north and south poles near one another as in Fig. 24 (*a*), the magnets will be drawn together.



*Attraction or Repulsion between Magnets.*

FIG. 24.

(2) **Like poles repel.** Thus the two magnets in Fig. 24 (*b*), with their north poles adjacent, will be repelled.

(3) A conductor under the influence of a magnetic field will always tend to place itself so as to embrace the maximum number of lines of force. Thus the piece of soft iron shown in Fig. 24 (*c*) will tend to move into the centre of the helix, where it can be traversed by as many lines of force as possible.

It will become magnetised itself in the process.

It is on this principle that all "solenoid" instruments work.

**89. Flux Density, Permeability and Reluctance.**—It has been stated that the strength of a magnetic field is measured in an arbitrary unit of so many lines of force per square cm.

In order to create this magnetic field, a certain **Magneto-Motive-Force** (M.M.F.) has to be exerted. Magneto-motive force depends upon the product of a current and the number of turns through which the current flows, *i.e.*, upon the number of "ampère-turns."

**Permeability.**—If an iron core is inserted in a solenoid it will be found that the flux will be increased perhaps a thousand times as much as with an air or any non-magnetic medium only, depending upon the quality of the iron and to what extent it fills the magnetic circuit. That is, with iron and any magnetic substance the magnetisation is not proportional to the magnetising force only, but depends on the nature of the iron and its degree of magnetisation.

This multiplying effect that the iron has on the flux is termed the "**permeability.**" It is the conducting or carrying power the iron has for the lines of force—similar to the conductivity of a conductor.

It is described as the ratio of the flux density in iron ("**B**" **lines per square centimetre**) to the flux density in air ("**H**" **lines per square centimetre**) with the same M.M.F.

The ratio B/H is represented by the symbol "$\mu$" (pronounced "mew") which is the "**coefficient of permeability.**"

$$\mu = \frac{B}{H} \text{ or } B = \mu H.$$

If the flux density in a coil be 10 lines per square centimetre, and, when an iron core is introduced, it is 15,000 lines, then for this specimen of iron, with the given M.M.F.,

$$\mu = \frac{B}{H} = \frac{15{,}000}{10} = 1{,}500.$$

$\mu = 1$ for air and for all non-magnetic substances.

Thus the iron under these circumstances is 1,500 times as good a carrier of lines of force as air: or, the æther is strained 1,500 times as much when the iron is present.

**90. Reluctance**—like resistance in an electric circuit—is the opposition which has to be overcome in a magnetic circuit before the flux can be established.

The reluctance, or magnetic resistance, of a piece of material depends upon its length, cross section, and permeability.

If "l" is the length of the magnetic path (Fig. 25), "a" the cross-sectional area in which the lines of force are going

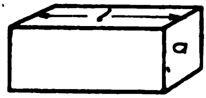


FIG. 25.

to be concentrated, and "$\mu$" the permeability of the substance used, then "S" (the reluctance) $=\frac{l}{a\mu}$. Then, if an M.M.F. is applied, the resulting flux is given by the following formula:—

$$\text{Magnetic flux} = \frac{\text{M.M.F.}}{\text{Reluctance}},$$

$$\textit{i.e.}, \Phi = \frac{\text{M.M.F.}}{\text{S}} = \frac{\text{M.M.F.} \times a\mu}{l}.$$

Also, the total flux ($\Phi$) is equal to the flux density per square centimetre (B) multiplied by the cross-sectional area (a).

Thus $\Phi = B \times a$.

For the coil or solenoid, which is always used in practice for the formation of electro-magnets, the magneto-motive force (M.M.F.) is equal to $\frac{4\pi \, IN}{10}$, where "I" is the current in ampères and "N" is the number of turns on the solenoid:—

$$\text{Hence flux} = \frac{\text{M.M.F.}}{\text{S}} = \frac{4\pi \, IN \, a\mu}{10 \, l}$$

$$\text{and from this } I \times N = \frac{10}{4\pi} \times \frac{\Phi l}{a\mu},$$

*i.e.*, ampère turns $= \frac{\cdot 8 \, \Phi \, l}{a\mu}$ (taking an approximation for $\pi$).

## MEASURING INSTRUMENTS.

**91.** Instruments used for measuring electric voltages and currents are called "Voltmeters" and "Ammeters." "Wattmeters" are used to measure the power in a circuit.

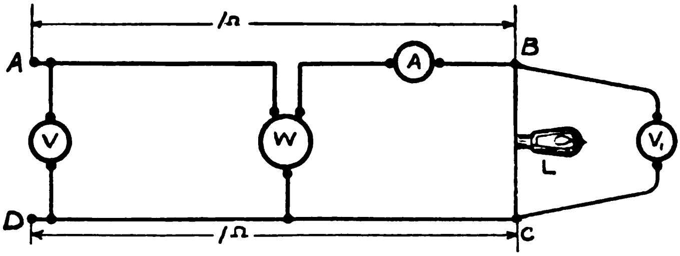
Essentially **a voltmeter** is an instrument used to measure the P.D. between the brushes of a dynamo, between the mains of a power system, or across a battery. It is designed to take as small a current as possible, and has a **high** internal resistance.

**An ammeter** is an instrument used to measure the current flowing in a circuit. It is joined in series with the mains at **any** convenient point.

Its resistance must be as **low** as possible, so that there will be a very small voltage drop in it.

**A galvanometer** is an instrument used to indicate when a current is flowing in a circuit, but it is not calibrated to read the value of the current in ampères.

**A wattmeter** measures the product of volts × ampères. It has one coil joined in series with one main, and one coil joined across the mains.



*Showing Method of connecting up Voltmeter, Ammeter and Wattmeter.*

FIG. 26.

**Example 10.**

Suppose between the two mains AB and CD a lamp L of resistance 108 ohms is joined.

Suppose the resistance of line A to B is 1 ohm, and the resistance C to D is 1 ohm. Suppose the P.D. between A and D is 110 volts.

Then the voltmeter V will read 110 volts.

$$\text{The current flowing will be } I = \frac{E}{R} = \frac{110}{108 + 2} = 1 \text{ ampère.}$$

This will be indicated by the ammeter A (which could equally well have been joined in the circuit between C and D).

As the voltage drop A to B, and C to D in each case $= I \times R = 1 \times 1 = 1$ volt, the P.D. between B and C $= 110 - 2 = 108$ volts; this will be indicated by the voltmeter $V_1$.

The wattmeter W would read $110 \times 1 = 110$ watts.

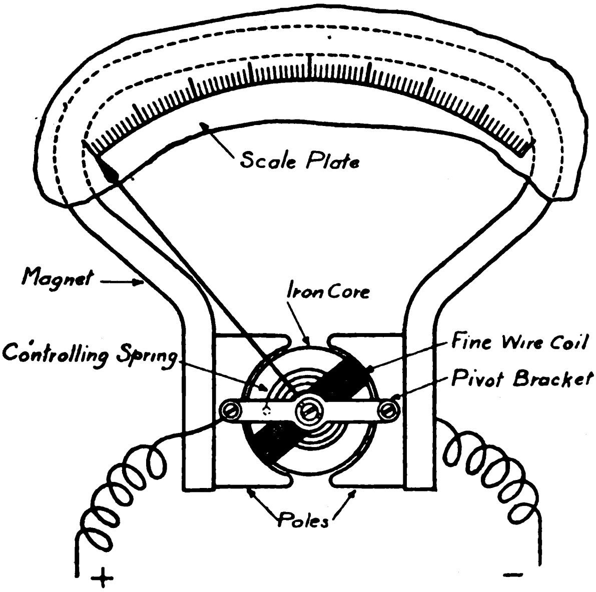
**92.** The types of Ammeter and Voltmeter generally used in service sets are moving coil instruments and hot wire instruments.

**Moving Coil Ammeter and Voltmeter.**—The working parts of each one are similar (Fig. 27).

A coil, energised by current from the circuit in which measurements are to be made, is free to rotate between the poles of a permanent horseshoe magnet.

The magnet has shaped pole pieces, between which—leaving narrow air-gaps—is a fixed iron cylinder to intensify the magnetic flux.

In the space between poles and cylinder the coil moves. It consists of a coil of fine insulated wire on a rectangular aluminium frame held by two pivots in jewelled bearings and carrying an aluminium pointer. Two spiral springs, the inner ends fixed to a pivot and the outer ends to the standing part of the instrument, return the pointer to zero position. They also serve to carry the current to and from the coil.



*Moving Coil Ammeter.*
FIG. 27.

The coil, when carrying current, tends to move so that its flux is at right angles to the magnet flux, thus enclosing as many lines of force as possible. That is, a "clock-wise" twisting torque (proportional to the current flowing) is exerted between magnet and coil against the "counter-clock-wise" torque of the springs. According to the strength of the current flowing, the pointer will take up a certain position on the scale.

The instrument is "dead-beat," *i.e.*, the pointer quickly comes to rest, owing to—

(1) the lightness of the moving parts;
(2) the currents induced in winding and aluminium frame as the coil moves through the flux.

**93. Ammeter.**—As the fine winding can only carry very small currents, the greater part of the current to be measured is shunted off by an "ammeter shunt" in parallel with the instruments.

The shunt is usually made of strips of alloy, *e.g.*, "manganin," and has a very low resistance, unaffected by temperature changes.

The resistance of the instruments and leads and of the shunt bear a definite ratio to one another.

Thus the instrument carries a definite fraction of the main current, but is graduated to register the main currents.

Note also that the combined resistance of ammeter and shunt in parallel is very small and has no appreciable effect on the resistance of, or the current in, the circuit.

Fig. 28 indicates how an ammeter may be joined up to measure the current flowing through the lamps shown.

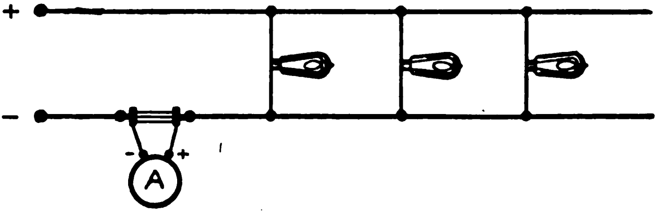


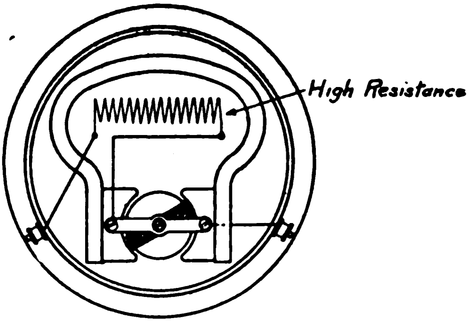
FIG. 28.

The ammeter terminals are always marked + and – ; the ammeter must be correctly joined in the circuit, *i.e.*, positive terminal to positive lead.

Shunts are not necessary with ammeters designed to measure very small currents.

**94. Voltmeter.**—A voltmeter is connected across two points in a circuit to measure their P.D.

In order that (1) it will not appreciably affect the resistance of the circuit and (2) it will carry only a small current, a high resistance (contained in the instrument) is put in series with it, as in Fig. 29.



*Moving Coil Voltmeter.*
FIG. 29.

Fig. 30 shows how a voltmeter may be used to measure the voltage applied to an accumulator under charge by a dynamo, or the voltage of the accumulator, while the ammeter, as shown, measures the charging current.

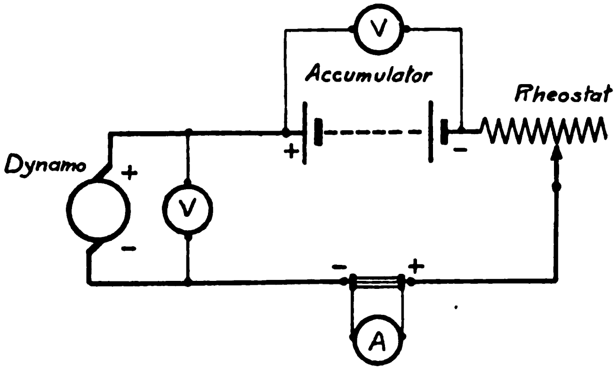
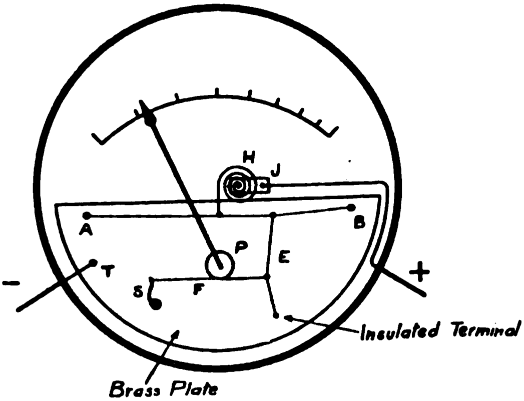


FIG. 30.

## 95. Hot Wire Ammeter and Voltmeter.—



*Hot Wire Ammeter.*

FIG. 31.

| | | | |
|---|---|---|---|
| A.B. | Platinum-silver bridge wire. | E. | Phosphor-bronze wire. |
| S. | Spring. | P. | Pulley and pointer. |
| F. | Silk fibre. | H. | Hair spring. |

**Action.**—Current enters at the block J and is carried by the hair spring H to the bridge wire AB, through which it divides to the terminals A and B, which are connected to a brass plate: current leaves by the terminal T, connected to the brass plate.

Near the centre of the bridge wire AB is attached a much thinner one E, which is fixed at its other end to an insulated terminal: to the wire E is attached a piece of silk fibre F, which is wrapped round a grooved metal roller P to which the pointer is fixed, the other end of the fibre terminating in an eyelet attachment to a flat spring S.

When current flows through the wire AB its sag increases, thus enabling the phosphor-bronze wire E to be more deflected.

The increased deflection of the latter is measured by the movement of the thin silk fibre F which turns the pulley and moves the pointer.

A damping device is attached to the spindle of the needle, generally consisting of a thin aluminium disc moving between the poles of a small strong permanent horseshoe magnet.

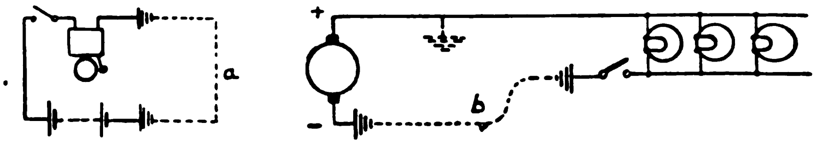
On motion taking place the current induced in the disc produces a magnetic field opposing the motion and thus delaying it.

The object of this disc is to damp out mechanical vibration.

For use as an ammeter, a shunt is used, as before, and for use as a voltmeter, a high resistance is fitted in series.

**96. Earth Return Circuits.**—The earth itself is a very good conductor of electricity; so also is the hull of a ship. Advantage is often taken of this fact by utilising an "earth return" as part of a circuit.

For example, in Fig. 32 (*a*), the battery shown is being used to ring a bell. The positive terminal of the battery is joined to the bell through a switch, but connection from the negative battery terminal is made by using an earth return between it and the bell.



*Earth Return Circuits.*
FIG. 32.

Similarly, in Fig. 32 (*b*), the dynamo is connected to a number of lamps in parallel through a single line wire, but the return connection is made by earthing the negative dynamo brush and one side of the switch.

This method of economising in wire can only be used in cases when you can be perfectly certain of the insulation of the single conductor.

If any earth were to develop on the line wire, as shown dotted, the dynamo would be short-circuited, an excessive current would flow, and the machine would be burnt out.

The earth has such a large cross-section that its resistance can be neglected. If the earth return is found to have an unduly high resistance, the fault probably lies in the method in which connection is made to earth.

Frequent use is made in W/T of earthed connections.

**97.** If a point in a circuit which contains a source of E.M.F. is earthed, electrons may have either to flow out of, or into, the earth. For example, if in Fig. 32 (*b*) the dynamo is developing a P.D. of 100 volts between its brushes, its positive brush will be at 100 volts potential above earth (or zero) potential.

A positive electrification denotes a deficiency of electrons, so that in this case electrons will flow from earth through the lamps, in at the positive brush, through the dynamo and back to earth at the negative brush.

If the brush connections are reversed, the brush connected to the line wire will be at 100 volts potential negative to earth, and the electron current is reversed in direction.

**98.** This question of potentials above and below earth is a frequent source of trouble in W/T.

A useful comparison is as follows:—

A child is playing on a beach. At one moment he takes water from the sea in a bucket and pours it out on the sand, when it runs back into the sea again, because he has raised it **above** sea level.

At another moment he digs a deep hole in the sand and the sea water "seeps" into it, because the hole is **below** sea level. In each case a movement of water occurs, though the directions of flow are different.

In W/T we are, as a rule, only concerned with producing an electron flow, and not with the direction in which it occurs.

Energy is required to vary the potential of any body above or below earth potential.

Similarly, energy has to be expended in either raising the temperature of water to (say) boiling point, or lowering it to (say) freezing point.

## CHAPTER III.

## INDUCTANCE AND CAPACITY.

**99. Electro-Magnetic Induction.**—We have already seen in Chapter II. that when a current of electricity flows along a wire the surrounding æther is subjected to a magnetic strain: in other words, the wire is surrounded by magnetic lines in the form of concentric circles.

There is a converse effect which we shall now proceed to study.

If a wire is surrounded by æther in a magnetic state of strain, and that magnetic strain suddenly changes in value, electrons will flow along the wire, and one end of it will momentarily be at a higher electrical potential than the other end.

A wire surrounded by magnetic lines of force, or placed in a magnetic field of lines of force, is said to be "interlinked" with the magnetic lines, so that we can describe the above phenomena in this way:—If a wire is interlinked with a magnetic field, and the number of magnetic lines interlinked with the wire changes, a momentary potential difference is set up between the two ends of the wire.

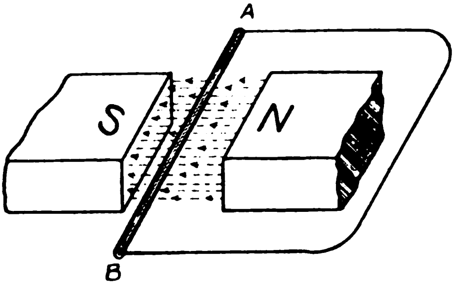


FIG. 33.

For example, suppose the conductor AB is moved upwards or downwards through the magnetic field between the poles N and S. Whenever it is moved the lines of force linked by the whole circuit will be varied, an E.M.F. will be set up in it, and current will flow.

This current is termed an "induced current," and the action occuring is termed "Induction."

If the conductor is moved downwards, it will be found that current will flow from B to A. If upwards, the flow of current will be from A towards B,

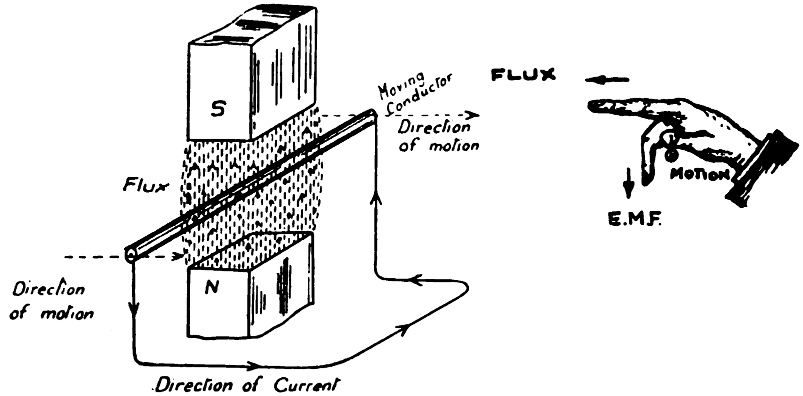
**100. Fleming's "Hand Rule"** is useful for determining the direction of an E.M.F. It is: use the **Right hand.** Extend the thumb, first finger, and the middle finger at right angles to one another as shown in Fig. 34.

Turn the hand into such a position—

(1) that the thumb points in the direction of the motion or equivalent motion of the conductor; and

(2) that the first finger points in the direction of the magnetic flux,

then the middle finger will point in the direction of the induced E.M.F.

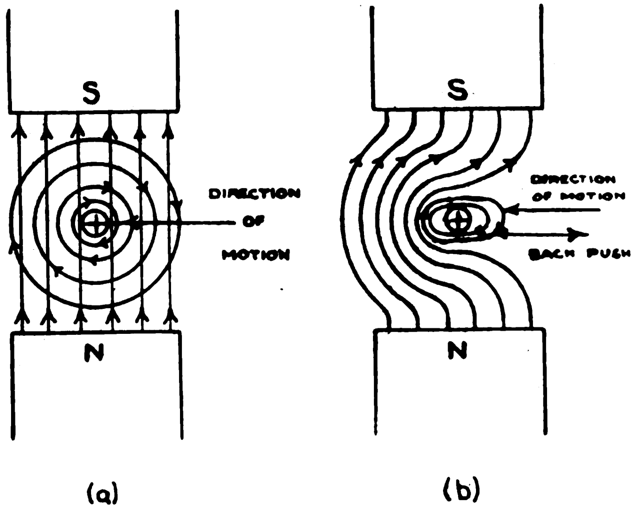


*Illustrating Fleming's "Hand Rule."*

Fig. 34.

**101. Lenz's Law.**—Force is required to move a conductor generating an induced E.M.F. and a current through a magnetic field, because the current flowing through the conductor sets up a flux around it which reacts on the flux which is being cut in such a manner as to oppose the motion of the conductor through the flux.

This is illustrated in Fig. 35.



*Illustrating reaction between current-carrying-conductor and Magnetic Field.*

Fig. 35.

If the conductor is moved through the field from right to left the induced current and its attendant field will be in the direction shown in Fig. 35 (*a*). In consequence, the circular lines round the conductor combine with the lines of the flux on one side of the conductor, as illustrated in Fig. 35 (*b*).

On the other side of the conductor, the circular force lines of the conductor and the lines of the field oppose one another. This tends to crowd the lines of the flux to one side of the conductor as shown, and to distort them.

The lines of force behave like taut rubber bands, and the distorted ones tend to straighten.

Hence they exert a force tending to expel the conductor from the field. This expelling force must be overcome if the conductor is to be moved through the flux.

This fact is expressed by **Lenz's Law**, which states that "electro-magnetically induced currents always have such a direction that the action of the magnetic fields set up by them tends to stop the motion that produces them."

From this it follows that energy must always be expended to produce an electron current by electro-magnetic induction.

By the mechanical energy expended in moving the conductor shown in Fig. 35 through the magnetic field, a current is made to flow through the resistance of the circuit; thus mechanical energy is turned into electrical energy.

**102.** A classification of the methods of producing induced E.M.F.'s may be made as follows:—

(1) Stationary flux and moving conductor.
(2) Moving flux and stationary conductor.
(3) Variable flux and stationary conductor.
(4) Variable flux and moving conductor.

Practically all cases where an E.M.F. is induced by a conductor being cut by lines of force will fall under one of the above classifications.

**103. The magnitude of the E.M.F.** induced depends on the **rate of cutting of lines of force.** That is, the greater the number of lines cut by a conductor in a given time, the greater will be the E.M.F. induced in the conductor.

It is evident from the above statement that there are several factors each of which in a measure determines the value of the E.M.F. induced. These are:—

(1) Speed with which the conductor moves through flux or with which flux moves past conductor. The greater the relative rate of movement of the conductor and magnetic field with respect to one another the greater the induced E.M.F.

(2) Strength of the field through which the conductor cuts. A greater E.M.F. will be induced in a conductor forced in a given time through a strong field than through a weak one.

(3) Angle of direction of conductor with respect to direction of field.

If a conductor being moved at a uniform speed cuts through the lines of a flux or field at right angles to the lines the rate of cutting of lines of force linked will be greater than if it cuts through them at any less angle. Hence the maximum E.M.F. is generated when the conductor cuts a given field at right angles.

(4) Length of the conductor which cuts lines.

The longer the conductor being moved in a field, the more lines it will cut per second, provided of course that the cutting conductor always lies wholly within the field.

**104.** To determine the voltage induced in a circuit, Faraday's Law may be used:—

$$\text{E.M.F. (volts)} = \frac{\text{Change of flux}}{10^8 \times \text{time in seconds}}.$$

If the number of lines through which the conductor is moved in t seconds is denoted by Φ, then the average E.M.F. induced is

$$\text{E (in volts)} = \frac{\Phi}{10^8 \times t}.$$

**Example 11.**

If the flux between the N and S pole faces of Fig. 34 is 800,000,000 lines, and the conductor is moved through this field in 1·5 seconds, what E.M.F. is induced in the conductor?

$$\Phi = 8 \times 10^8$$

$$E = \frac{\Phi}{t \times 10^8} = \frac{(8 \times 10^8)}{1{\cdot}5 \times 10^8} = \frac{8}{1{\cdot}5} = 5{\cdot}3 \text{ volts.}$$

**105.** If a coil consisting of N turns is moved through a uniform field, the total E.M.F. induced in each turn will assist in forcing current round the circuit. Thus the E.M.F. induced in a coil of N turns moving through a field of Φ lines of force after t seconds will be

$$E = \frac{\Phi \times N}{t \times 10^8}.$$

**Example 12.**

If a coil of 400 turns be moved through a field of 100,000 lines in one second, find the E.M.F. induced across the coil.

$$E = \frac{400 \times 10^5}{1 \times 10^8} = \frac{4}{10} = \cdot 4 \text{ volt.}$$

## SELF-INDUCTION.

**106.** When a conductor is "cut" by its own lines of force, *i.e.*, when the lines of force associated with its current vary in number due to the current changing its strength, then an E.M.F. will be induced in the conductor.

Under any circumstances there are only two cases to be considered

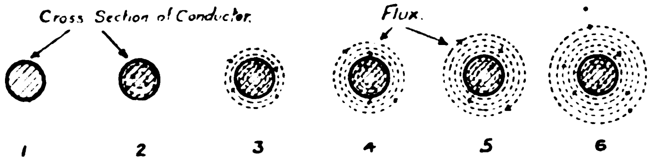
(*a*) when current is increasing,
(*b*) when current is decreasing.

Consider a D.C. circuit, or a portion of it, consisting of a single conductor, and let current be switched on.

A short interval of time will elapse before the current attains its maximum and steady value—just as, with all bodies, it takes time to produce speed in them.

In this interval of time in which the current and the lines of force are increasing in magnitude, the conductor will be cut by all the lines of force as they emanate from the centre of the conductor and expand in the form of concentric circles in and around it. Thus the conductor will be cut at every instant in this space of time by an increasing number of lines of force, and an E.M.F. (varying in value from one instant to another) will be induced in it. This induced E.M.F. is termed the "**E.M.F. of self-induction,**" and the action occurring is termed "Self Induction."

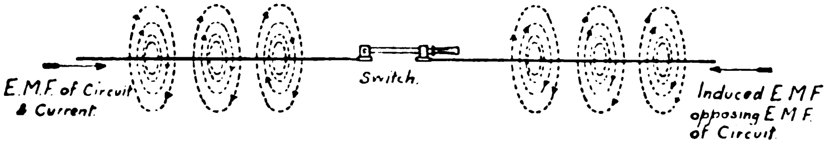
This is illustrated in Fig. 36.



*Growth of Current and Magnetic Field.*

FIG. 36.

**107. Direction of Induced E.M.F.**—From Lenz's Law (*see* para. **101**) we may deduce that the induced E.M.F. will act in opposition to the E.M.F. applied to the circuit, and thus delay the growth of the current.

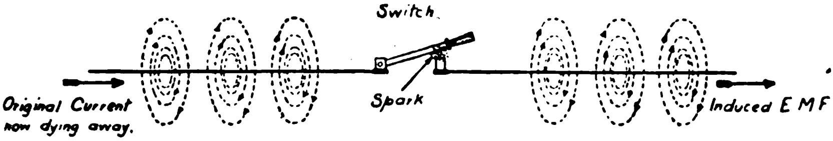

E.M.F. of Circuit & Current.
Switch.
Induced E.M.F opposing E.M.F. of Circuit.

*Magnetic Field growing.*

FIG. 37.

When the current reaches its maximum steady value the lines of force cease to increase and lie steadily round the conductor, cutting it no longer: hence there will be no E.M.F. induced when the current is steady.

When the circuit is broken, as by the switch in Fig. 38, the current and the attendant lines of force take time to fall to zero value.



*Magnetic Field dying away.*

FIG. 38.

The circuit is cut by the decreasing lines of force as they collapse inwards, hence an induced E.M.F. appears again.

By Lenz's Law, the induced E.M.F. will oppose the cause producing it, *i.e.*, will oppose the decrease of current and flux.

That is, its effect is to endeavour to keep the original current flowing.

In consequence, where the circuit is broken a spark will appear which represents the endeavour of the original current to continue.

The induced E.M.F. together with the applied E.M.F. act across the break or gap in the circuit, overcome the resistance of the air-gap, and cause a current in the form of a spark—*i.e.*, a convection current—to flow across it.

It lasts until the current, flux and induced E.M.F. have died away.

**To sum up; the effect of self-induction only occurs when the current is changing—increasing or decreasing—and when the current is changing the effect of self-induction must always be present.**

The effect of self-induction is always to oppose an increase or oppose a decrease in the current; **that is, it always opposes a change in the direction or strength of the current.**

**108.** These effects remind us exactly of those with which we are familiar in the starting of a body from rest and in its change of motion.

(The notes in Appendix A on Inertia, Momentum and Energy, applied to Mechanics, should be referred to.)

Consider a number of porters shunting a railway truck by hand. It is not a bit of good for one of them to give the truck a kick; that would not move it. They have to push against it steadily until they have overcome its "inertia" or disinclination to move, and get it under way. Once under way—at, say, one mile per hour—their work is much easier; they only have to overcome the frictional losses at its axles, wheels, &c.

When they want to stop it, they have to push against it just as hard as ever they did to start it up; or, more simply, they put its brakes on, and expend its "kinetic energy"—*i.e.*, the energy it possesses by virtue of its motion—in the form of heat, generated by the friction of the brakes.

**109.** Similarly with the electric current.

When the circuit is made, part of the applied voltage is employed in overcoming the E.M.F. of self-induction, and part in driving the current through the ohmic resistance (like friction). While the former lasts, energy is being given to the circuit and is stored up in the magnetic field. Finally by the time that the current reaches its maximum value, the induced E.M.F. has fallen to zero, and the applied voltage is solely devoted to driving the current through the resistance.

When the circuit is broken, the electrical inertia, or inductance of the circuit, objects to a decrease of current and before the current can be reduced or stopped this energy must be partly or wholly removed—in the form of heat at the "break" in the circuit.

In D.C. circuits, the inductive effects are in operation only on switching on and off, or when changing the resistance and thereby the current.

In A.C. circuits, in which the currents are continually changing in strength and direction, inductive effects are continually present.

**110.** As a reminder that an electric current is a stream of electrons through a wire, we may sum up the foregoing facts as follows:—

The relations between the electron and the external field of energy that attends its motion are perfectly reciprocal.

On the one hand, the electron cannot move from rest without this attendant field of energy around it coming into existence, and cannot be stopped without this attendant field of energy disappearing from the æther.

On the other hand, the creation of a magnetic field in space endows, or tends to endow, all the electrons in that space with motion in one direction, and the cessation of the magnetic field endows, or tends to endow, them with motion in the opposite direction.

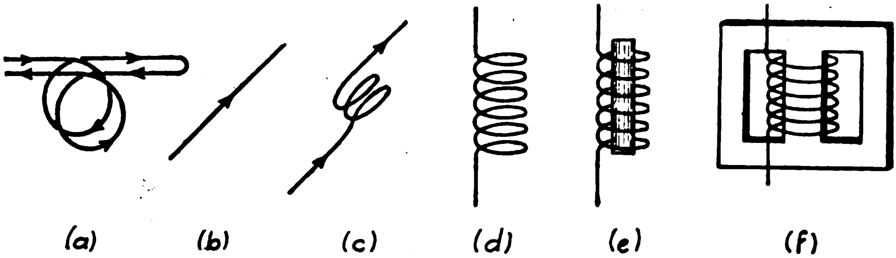
A steady current of electricity, or flow of electrons in a circuit produces no change in the surrounding magnetic field.

A steady magnetic field produces no movement of electrons within it, and no electric current.

Electrons changing the speed or direction of their motion produce attendant changes in the surrounding magnetic field, and conversely a change in the direction or strength of a magnetic field produces motion or tendency to motion of the contained electrons.

**111. What Inductance depends on.**—The inductance of a length of wire depends upon the form it takes—how it is arranged or wound.

If left "single," so that lines of force from one part of it do not interlink with another part, its inductance will be small, because the amount of cutting or interlinking must be small. (Fig. 39 (*b*).)



*Various forms of Inductance.*

FIG. 39.

If the wire is carried back on itself (Fig. 39 (*a*) )—in a bight —and wound in any form, the magnetic field of force of one half will neutralise that of the other, and the circuit will be "non-inductive." (Resistances used in measuring instruments, and rheostats, are wound in this way.)

If the wire is wound into a coil (Figs. 39 (*c*) and (*d*) ), the inductance is greatly increased, as the flux of the turn not only interlinks with that turn but with neighbouring turns, *i.e.*, the amount of interlinking is greatly increased.

Again, in the case of a coil with an iron core (Figs. 39 (*e*) and (*f*) ), the latter has a multiplying effect on the flux and the interlinkages and inductance are increased to a still greater extent.

Thus the various diagrams in Fig. 39 are ranged from left to right in order of their inductance, (*a*) having no inductance, and (*f*) having most.

A circuit containing a powerful electro-magnet is termed "highly inductive"; such a circuit would be the field magnet circuit of a motor. On making such a circuit there are no undesirable effects set up, but on breaking it precautions must be taken, as the spark at the break—*i.e.*, the outlet for the large amount of energy in the magnetic field—will be powerful and persistent, and may cause damage to contacts or insulation.

Kicking coils, magnetic blow outs, safety horns, &c., are used to obviate these undesirable effects.

**112. Inductance.**—If the magnetic path inside and outside a coil has constant permeability, the flux due to a current I through the coil will be proportional to I.

*i.e.*, Flux due to a current I = kI, where k is a constant.

If N be the number of turns in the coil, the **flux linkage** will be kNI.

From Faraday's Law, the induced E.M.F. is proportional to **the rate of change of flux linkage.**

If the E.M.F. be measured in volts and the current I in ampères, this may be written—

$$E = -\text{rate of change of } kNI$$

(the negative sign meaning that the induced voltage is in opposition to the applied voltage, causing the current change).

But k and N are constants.

$$\text{Therefore } E = -kN \times \text{rate of change of I.}$$

or, writing $L = kN$.

$$E = -L \times \text{rate of change of I.}$$

**The constant L is called the "self-inductance"** or co-efficient of self-induction of the coil.

It is permissible and usual to say "inductance" when "self-inductance" is meant, but it is very important to avoid confusion between the two words "induction" and "inductance." As will be seen from the definitions above, induction varies with the rate of change of flux linkages, while inductance is a fixed invariable quantity, depending on the shape and number of turns of a coil, and independent of the current passing through the coil (provided there is no iron present).

### 113. Unit of Self-inductance.

From the definition given above, it will be seen that

$$L = \frac{\text{induced E.M.F.}}{\text{rate of change of I}}.$$

**A coil is said to have unit self-inductance, if the E.M.F. induced across it is one volt when the current is changing at the rate of one ampère per second.**

**This unit of self-inductance is called a "henry."**

Various subdivisions of the henry in use are:—

The **Millihenry,** or a thousandth of a henry (symbol m H),

The **Microhenry** (abbreviated "mic") or a millionth of a henry (symbol $\mu$ H),

The **Centimetre** (the electro-magnetic or absolute unit) or a thousand millionth of a henry (symbol cm.).

Thus 1 henry $= 10^3$ millihenries,
$= 10^6$ microhenries or mics,
$= 10^9$ c.m. or absolute units or centimetres.

There are, therefore, $10^3$ cms. in 1 mic.

The inductance of a coil is always denoted by the letter **L.**

### Example 13.

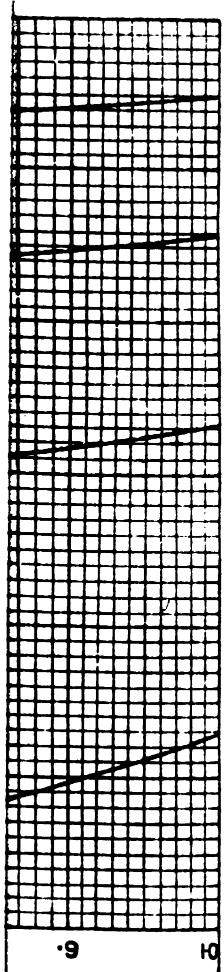
In a circuit for which $L = 0 \cdot 5$ henry, and in which current is growing uniformly at the rate of two ampères per second, then E (the counter E.M.F. of self-induction) $= -0 \cdot 5 \times 2 = -1$ volt.

(The **negative sign** merely denotes that the induced E.M.F. acts in opposition to the change of current.)

If the rate of growth of current were quicker, as, for example,

e para 115)

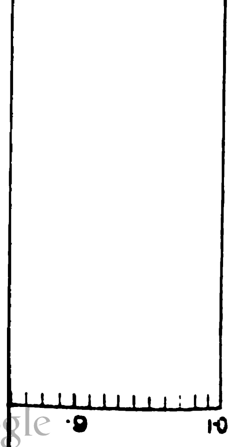
70.



RVE FOR

RE LAYERS.

x (turns)$^2$



Malby & Sons, Lith.

if the current were growing at the rate of 2 ampères in $\frac{1}{100}$ of a second, then

$$E = -0 \cdot 5 \times \frac{2}{\cdot 01} = -100 \text{ volts.}$$

If the rate of dying away of current be taken, and if it be very rapid, then the forward E.M.F. will be very large: For example, if the current were dying away at the rate of 2 ampères in $\frac{1}{1000}$ of a sec., then

$$E = -0 \cdot 5 \times -\frac{2}{\cdot 001} = +1{,}000 \text{ volts.}$$

### 114. Derivation of the henry.

From the statement above that flux due to a current $I = k\,I$, we see that when absolute unit current is flowing through the coil—

$k =$ flux per absolute unit current through the coil.

If S be the reluctance of the magnetic circuit

$$\text{Flux} = \frac{M\,M\,F}{S} = \frac{4\,\pi\,I\,N}{S}. \quad (\textit{See} \text{ para. } \mathbf{90}.)$$

$$\text{Therefore } k = \text{flux per unit current} = \frac{4\,\pi\,N}{S}.$$

Further, since $L = k\,N$,

$$L \text{ (in absolute units)} = \frac{4\,\pi\,N}{S} \times N = \frac{4\,\pi\,N^2}{S}.$$

Thus L varies as $N^2$; 4, $\pi$ and S being constants.

This is transformed into practical units by dividing by $10^9$.

$$\text{Thus } L \text{ (in henries)} = \frac{4\,\pi\,N^2}{10^9 \times S}.$$

**115. Calculation of Inductance.**—The calculation of the inductance of a given coil is a complicated matter, because the **relative** effect of the flux generated by each turn of the coil **upon every other turn** has to be considered.

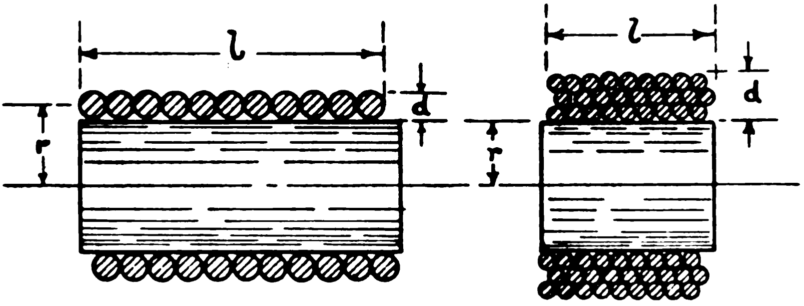
The inductance of a coil of wire wound on a former of unit permeability—*i.e.*, a non-magnetic substance such as wood, ebonite, glass, &c.—may be found with the help of the following formula, and the curve given in Fig. 40.

$$\mathbf{L = r \times N^2 \times F} \textbf{ mics.}$$

where
$r =$ the mean radius of the coil in inches.
$l =$ the winding length in inches.
$d =$ the depth of the winding in inches, or the thickness of the wire used in a single layer coil.
$N =$ the number of turns in the coil.
$F =$ the "form factor" of the coil, and is found from the curve in Fig. 40, after the ratio $\frac{r}{l + d}$ has been determined.

The above data can be obtained in the following manner:—

(1) Measure the radius of the former and add half the depth of the winding, Fig. 41 (*b*), or half the diameter of the wire used, Fig. 41 (*a*); or, measure the circumference of the former, divide by $2\pi$, and add half the depth of the winding. This gives "r."



(a) (b)

FIG. 41.

(2) Measure the total winding length of the coil in inches. This gives "l."

(3) Count the total number of turns in the coil; or, if there are a great many turns count the number in say, one inch of winding length and multiply by l. This gives "N."

(4) Determine "d," the depth of the winding. In a single layer coil this will be the diameter of the wire used.

(5) Work out the ratio $\frac{r}{l + d}$.

(6) Find the value of F from the curve corresponding to the ratio $\frac{r}{l + d}$, being careful to work on the right part of the curve, and to read the scale very accurately.

For values of $\frac{r}{l + d}$ which are between 4 and 8, the value of F can be found thus: divide $\frac{r}{l + d}$ by 2; look up the value of F corresponding to this, add ·0220 to this value, and the answer will be the correct value of F.

(7) Work out the formula—

$$L = r \times N^2 \times F \text{ mics.}$$

**Example 14.**

It is required to determine the inductance of a single layer coil of 64 turns of wire ·08 in. in diameter, wound on a former of 2·65 in. radius, for a winding length of 16·2 inches.

| | | |
|---|---|---|
| (1) | Radius of former | = 2·65 in. |
| | half diameter of wire | = ·04 in. |
| | Mean radius of coil | = 2·69 in. |

(2) l = 16·2 inches.

(3) N = 64 turns.

(4) d = ·08 inches.

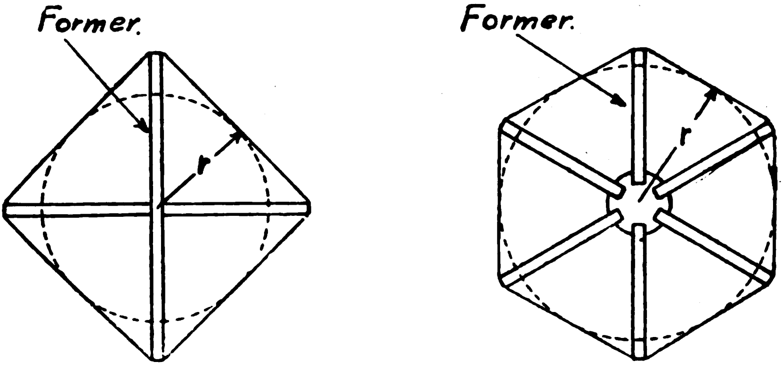
(5) $\frac{r}{l + d} = \frac{2 \cdot 69}{16 \cdot 2 + \cdot 08} = \frac{2 \cdot 69}{16 \cdot 28} = \cdot 1653.$

(6) F = ·0145 (from the lowest curve).

(7) $L = 2 \cdot 69 \times 64^2 \times \cdot 0145 = 160$ mics.

If the coil is wound on a former having a square cross section (Fig. 42 (*a*) ) instead of on a cylinder, its self-inductance will be from 22 per cent. to 27½ per cent. greater than that of the corresponding cylindrical coil which would be bounded by the circle inscribed in the square that forms the boundary of the coil.

If the coil is wound on a hexagonal (six-sided) former (Fig. 42 (*b*) its self-inductance will be about 10 per cent. greater than that of the corresponding cylindrical coil which would be bounded by the circle inscribed in the hexagon bounding the coil.



(*a*) Fig. 42. (*b*)

In order to obtain the maximum self-inductance with the minimum length of wire, the diameter of the coil should be 2·414 of the winding length.

**To wind a coil of given self-inductance.**—The problem of calculating self-inductance is usually presented to us in another form.

Instead of having to find the inductance of a given coil of wire, we have usually to **wind a coil of given self-inductance.**

Having first selected a former and the size of wire necessary, we wrap some of the wire round the former with the same spacing (if any) that we are going to use in the finished coil. We then measure the axial length occupied by 10, 20 or more turns, taking the measurements in inches.

Suppose we have an idea that somewhere between 100 and 200 turns will be correct for our particular inductance.

Assume 100, 130, 160 and 200 turns, working out the inductance in each case. Probably, none of these numbers will be the exact number of mics we require.

By making a rough curve of mics and turns we can then pick out fairly exactly the number of turns necessary.

From the formula given above it may be deduced that the more closely the turns are spaced, and the greater the diameter of the coil, the greater will be its inductance.

It is not so easy a matter to calculate the inductance of a coil wound on an iron core, since the reluctance of the various magnetic paths has to be taken into account.

The method of making this calculation is given in any standard electrical text-book.

**116. Energy stored in Magnetic Field.**—When a magnetic field is created round an inductance, a certain expenditure of energy is necessary, over and above the energy expended in forcing current through the resistance of the coil. When the magnetic field collapses on the current falling in value, this energy is restored to the circuit again, causing the current to continue for a longer time than it would otherwise have done.

This energy is therefore stored in the magnetic field round the inductance.

Suppose we wish to determine the work done in creating a current of maximum value $I_m$ ampères in a circuit of self-inductance L (henries) in a time t.

The counter E.M.F. of self-inductance when the current is varied at the rate of $\frac{I_m}{t}$ ampères per second $= \frac{L \times I_m}{t}$ volts.

The mean value of the current which starts at zero and rises to a maximum value of $I_m$ ampères is $\frac{1}{2} I_m$.

Hence the work done, and energy expended in creating the magnetic field, which we saw in para. **58** to be the product of E.M.F., current and time, will be

$$\frac{L \times I_m}{t} \times \tfrac{1}{2} I_m \times t = \tfrac{1}{2} L I^2_m \text{ joules.}$$

Since the factor of time does not appear in the result, it is clear that the same amount of work is required to create a given current in a circuit of given self-inductance whether it is created slowly or quickly.

The **energy stored** in the magnetic field round an inductance thus = **$\frac{1}{2}$ LI$^2_m$ joules.**

Hence the greater the inductance of the circuit and the greater the current, the greater will be the amount of energy stored in it—to be given up again in some form when the current is reduced or stopped.

**117. Various forms of Inductance.**—Inductances met with in W/T take various forms. These may be classified as :—

(*a*) Inductances having a maximum of inductance (of the order of henries) in a minimum of space, and a large current-carrying capacity. These will have iron cores. Such are armatures and field coils of motors, dynamos and alternators, transformers, induction coils, &c.

(*b*) Inductances of a very small value, having very low resistance, very large current-carrying capacity, and very high insulation between adjacent turns. Such are the primaries of spark oscillators.

(*c*) Inductances of much larger value, slightly more resistance, less current-carrying capacity, and less insulation between adjacent turns than (*b*). Such are the aerial coils of spark and continuous wave sets.

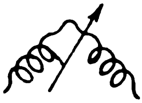
(*d*) Inductances of large value of the order of mics, of small diameter wire and low insulation between turns, adjustable in steps. Such are the inductances used in receiving circuits.

(*e*) **Variometer Inductances.**—A variometer inductance is composed of two coils joined in series : one is fixed and the other can be rotated inside the fixed one. When in one position the direction of the windings of the two coils is such that the field produced by one annuls nearly all the field due to the other and the inductance of the two coils is a minimum.

When the moving coil is rotated through 180° from this position the fields produced by these two coils assist one another, and the inductance of the two coils is a maximum.

Thus a variometer affords a very delicate variation of inductance.

A variometer is indicated diagrammatically as in Fig. 43.



*Variometer.*

Fig. 43.

**118. Inductances in series and parallel.**—If two or more inductances are joined **in series,** as in Fig. 44 (*a*) their total effective inductance can be found by adding their several inductances together :—

Thus L (the total inductance)
$=L_1 + L_2 + L_3 +$ &c.

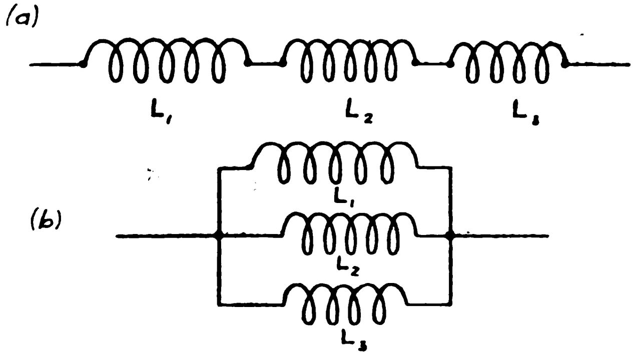


FIG. 44.

If they are joined **in parallel,** as in Fig. 44 (*b*), their joint inductance is such that $\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} +$ &c.

Their joint effect in opposing the rise or fall of current is decreased in the same way that the joint resistance of several resistances joined in parallel is decreased.

This statement is proved in Chapter V., para. **222.**

## MUTUAL INDUCTION.

**119. Mutual Induction.**—If a second circuit containing inductance be brought near a circuit carrying a current (Fig. 45), the flux due to the current in the first circuit will cut the second.

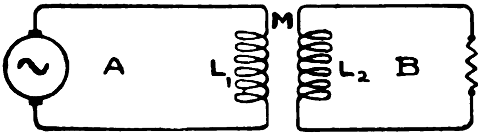


FIG. 45.

Any change in the current in the first circuit will produce a change in the flux linkage with the second circuit, and therefore an E.M.F. will be set up in this circuit.

This phenomenon is known as " mutual induction."

Any two circuits between which there is mutual induction are said to be " magnetically or inductively coupled."

Consider the case of two circuits coupled together magnetically.

Let us assume that the current in circuit A is an "alternating current," *i.e.*, one that is continually varying in strength and direction (*see* Chapter IV.).

In circuit A, Fig. 45, let the E.M.F. be $E_1$ and the current $I_1$; in circuit B, let the induced voltage be $E_2$. Also let the number of turns in the two coils, $L_1$, $L_2$, coupled be $N_1$, $N_2$.

With the same assumptions as before, let $k\ I_1$ denote the flux passing through $N_2$ due to the current $I_1$.

Now $E_2$ is the E.M.F. due to the variation of current $I_1$.

Therefore $E_2 = -$rate of change of $(k\ I_1 \times N_2)$.
$= -k\ N_2 \times$ rate of change of $I_1$
since both $k_1$ and $N_2$ are constants.

Similarly, if $E_1$ is a voltage induced in circuit A by a varying current $I_2$ in circuit B, we can show that

$E_1 = -\ k_2 \times N_1 \times$ rate of change of $I_2$.

It will be found in practice and may be shown theoretically that under all circumstances

$$k_1 \times N_2 = k_2 \times N_1.$$

Let each be denoted by M.

Then $E_2 = -M \times$ rate of change of $I_1$.
$E_1 = -M \times$ rate of change of $I_2$.

This constant M is called the "mutual inductance" or "coefficient of mutual induction."

**120. Coefficient of Mutual Induction.**—The closer two coils are wound together, and the better the magnetic path for the lines of force, the greater will be the E.M.F. induced in one circuit for any change of current through the other circuit.

**Definition.**—A pair of circuits are said to have mutual inductance or a coefficient of mutual induction of **one henry** when current changing in one circuit at the rate of **one ampère per second** produces in the other an **E.M.F. of one volt.**

Thus mutual inductance is measured in henries, millihenries, microhenries, &c., just as self-inductance is.

It is denoted by the letter "**M**" and is a measure of the lines of force linked between the two circuits for a given current in one.

**Example 15.**

Assume that the mutual inductance between coils A and B in Fig. 45 is 5 mics, and that the current through A rises from zero to 10 ampères in 0·3 second, then the voltage induced across coil B will be

$$E_2 = \frac{5}{10^6} \times \frac{10}{\cdot 3} = 1\cdot 7 \times 10^{-4} = \cdot 00017 \text{ volt or } 1\cdot 7 \text{ millivolts.}$$

**121.** Circuits are said to be **coupled together, loosely or tightly,** by reason of their mutual induction.

Thus Fig. 46 shows two coils which have greater and greater mutual induction, and are coupled together more and more tightly, taking them from left to right.

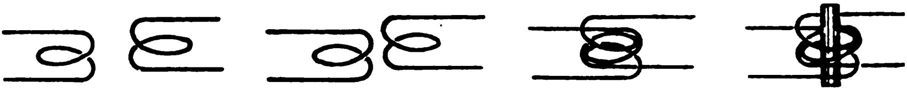


FIG. 46.

If two coils are so placed relatively to one another that the flux from one coil cannot thread through the other at all, then there will be no mutual induction, and no induced E.M.F.s.

**122. Derivation of M.**—In exactly the same way as was adopted for the derivation of L, we may show that the flux due to circuit A $= \frac{4\pi N_1}{S}$ for unit current through it.

Therefore the linkages with circuit B

$$= \text{flux} \times \text{turns} = \frac{4\pi N_1}{S} \times N_2.$$

$$\text{Therefore M (in absolute units)} = \frac{4\pi N_1 N_2}{S}$$

$$\text{and M in henries} = \frac{4\pi N_1 N_2}{10^9 \times S}.$$

**123. Coupling Factor.**—Since 4, $\pi$, $10^9$ and S are constants, M varies as $N_1$ and $N_2$:

Since the inductance of a coil varies with the square of the number of its turns (para. **114**), the inductance of the coils —$L_1$ and $L_2$—containing the turns $N_1$ and $N_2$ vary as $N_1^2$ and $N_2^2$:

Hence M varies as $\sqrt{L_1}$ and $\sqrt{L_2}$

or $M \propto \sqrt{L_1 L_2}$.

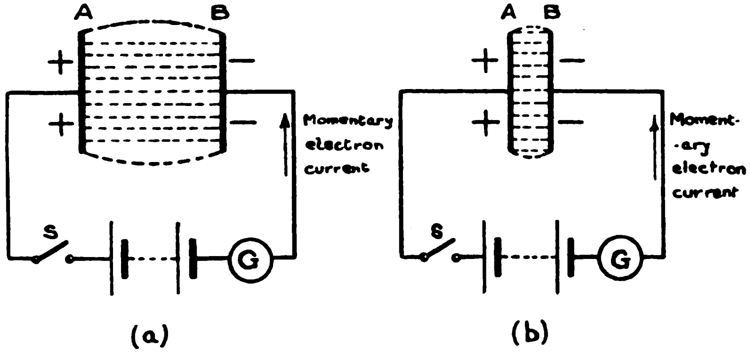
or $M = k\sqrt{L_1 L_2}$, where k is a constant.

The constant k is known as the "coupling factor" (*see* Chapter IV., para. **269**).

## THE CONDENSER.

**124.** Suppose the two conducting plates A and B (Fig. 47 (*a*) ), are connected to a battery and galvanometer through the switch S.

(*a*) When the plates are well separated, as soon as the switch S is closed the battery will cause a momentary rush of electrons round the circuit from Plate A., which is connected to the positive terminal of the battery, through the battery towards Plate B, where they will crowd together; the galvanometer G will give a kick. The current will stop as soon as the potential difference between the plates is equal to the terminal P.D. of the battery.



(a) (b)

Fig. 47.

Plate B will be crowded with electrons which will repel others trying to arrive. The atoms of Plate A have lost electrons and are, therefore, positive ions, which, by their attraction, prevent any more electrons from moving away. Equilibrium is thus established.

(*b*) Let the two plates be suddenly brought closer together.

The positive ions on Plate A now make their influence felt on Plate B; their field annuls some of the field of the electrons crowded there.

Similarly, the field of the electrons on Plate B annuls some of the field due to the positive ions on Plate A.

The potentials of the two plates are therefore momentarily lowered, the forces holding the electrons in check are decreased, and another momentary electron movement takes place until equilibrium is again established, and the P.D. between the plates is again equal to the terminal P.D. of the battery.

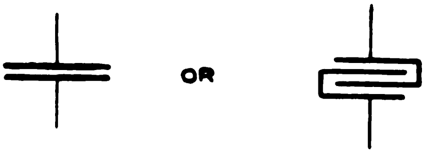
Notice also that the electrons in the atoms of the dielectric between the plates are strained towards the positive plate and away from the negative plate; they cannot, however, move out of their atoms by reason of the nature of atoms which compose a dielectric (para. 37); they can only move a little.

When the plates are brought nearer together, the field density acting across the dielectric is increased, and the strain on these electrons becomes greater.

Hence the dielectric plays a definite part in the operation.

**125.** An arrangement of this sort is termed a Condenser. A condenser consists of two or more conducting plates separated by a dielectric—either air or some other insulating substance.

A condenser is illustrated diagrammatically as in Fig. 48.



*Condenser of the order of jars or centimetres.*

*Condenser of the order of microfarads.*

Fig. 48.

From the foregoing, it can be seen that a momentary charging current will flow until the P.D. between the plates is equal to the applied E.M.F.

To continue the argument.

**126.** (*c*) Suppose we break the switch S; then the condenser will be left charged with a certain quantity of electricity.

A condenser is therefore said to have **capacity,** or ability to hold electricity. This capacity depends on—

(*a*) the area of the plates;

(*b*) the closeness of the plates;

(*c*) the nature of the dielectric.

**127.** (*d*) If the battery B is now short-circuited and the switch S again closed, the electrons will rush back from the negative plate to the positive plate until they are equally distributed round the circuit, and there will be a kick shown on the galvanometer in the reverse direction.

The electrons in the dielectric, which were strained towards the positive plate, will flick back into their proper places.

There will thus be a momentary conduction current (para. **39**) round the circuit, and a displacement current (para. **40**) through the dielectric.

Clearly, the greater the voltage applied to the condenser the greater will be the electric strain across the dielectrics.

The greater the dielectric strain the greater will be the amount of electrical energy stored in the condenser.

Similarly with a steel spring, the greater the strain in it, the greater the amount of mechanical energy stored up, which is liberated by the uncoiling of the spring.

**128. Capacity.—The Capacity—symbol C—of a condenser** is its ability to store up electrical energy.

It is measured by the quantity of electricity to establish unit P.D. between its plates.

The practical unit is the **Farad.**

A condenser has a capacity of **one farad** when a charge of **one coulomb** (or one ampère flowing for one second) charges it to a P.D. of **one volt.**

A farad is, for convenience, subdivided into the following smaller units :—

1 farad $= 10^3$ (a thousand) " **millifarads** " (mF).
$= 10^6$ (a million) " **microfarads** " ($\mu$F).
$= 10^{12}$ " **micromicrofarads** " ($\mu\mu$F).
$= 9 \times 10^8$ (nine hundred million) **jars.**
$= 9 \times 10^{11}$ **absolute units, or cms.**

It will be seen that $10^3$ cms. = 1 jar.

$$1 \text{ jar} = \frac{1}{900}\,\mu\text{F}.$$
$$= \frac{1}{9 \times 10^8}\text{ Farad.}$$

The Jar is the Service unit, and is very useful when dealing with the small capacities met with in ordinary practice.

**129.** The following relationship is very important and is derived from the above definitions :—

$$Q = CV \text{ where} \begin{cases} Q = \text{coulombs.} \\ C = \text{farads.} \\ V = \text{volts.} \end{cases}$$

That is, the charge introduced into a condenser is proportional to the capacity of the condenser and the voltage to which it is charged.

The formula may be written :—

$$V = \frac{Q}{C}.$$

That is, the P.D. between the plates of a condenser is directly proportional to the charge introduced and inversely proportional to the capacity of the condenser.

Thus a charge of 5 coulombs introduced into a condenser of ·5 farad would create a P.D. between its plates of $\frac{5}{\cdot 5} = 10$ volts : if introduced into a condenser of ·005 farad it would create a P.D. of 1,000 volts.

**130. Energy stored in a Condenser.**—Just as when a magnetic field is created round an inductance a certain amount of energy is stored in the magnetic field in the form of electro-magnetic lines of strain, so, when a condenser (C) is charged up to a certain maximum voltage V, energy is stored in the creation of the electric field between the plates.

When the condenser discharges, this energy is restored perfectly to the circuit.

Thus, in the charge and discharge of a condenser there is no expenditure of energy if the condenser is perfectly efficient, *i.e.*, if all the charge put into the condenser is returned by it.

The total quantity of electricity in coulombs introduced into a condenser of C farads charged to a maximum potential of $V_m$ volts $= Q = CV_m$.

The charging current is a measure of coulombs per second, and therefore is equal to $\frac{Q}{t} = \frac{CV_m}{t}$. Now it was stated in para. **58** that energy, or work done on a circuit, is found by multiplying together voltage, current, and time, *i.e.*, joules $= V \times I \times t$.

In this case the voltage will be the **average** voltage during charge, which will be $\frac{1}{2}V_m$.

Thus the total work done during time **t** must equal $\frac{1}{2}V_m \times \frac{CV_m}{t} \times t = \frac{1}{2}CV_m^2$ joules.

This is then the amount of energy expended in charging a condenser of C farads to a maximum pressure of $V_m$ volts, and is also the amount of energy stored in the condenser when charged.

**131. Power taken in charging a Condenser.**—If a condenser is charged or discharged N times per second, a power of $\frac{1}{2}CV_m^2 \times N$ joules per second will be required.

But joules per second = watts (para. **58**).

Hence the power required to charge a condenser N times per second—

$$= \tfrac{1}{2}CV_m^2 N \text{ watts.}$$

**132.** The capacity of a condenser is a **fixed quantity.**

A condenser may be compared with an iron gas cylinder. To increase the quantity of gas pumped into it an increased pressure must be applied.

At first the gas passes easily, but the more gas is pumped in the harder it is to force in more.

At any moment the internal pressure equals the applied pressure.

**133. Specific Inductive Capacity.**—Different dielectrics act differently as regards the inductive action between the plates.

For instance, mica will suffer a greater electric strain than air, or a more powerful inductive action takes place across it.

If mica be substituted for air in a condenser a greater charge can be given before the P.D. is raised to that of the supply terminals.

The " mica condenser " has a larger capacity.

This property of the dielectric is termed its " Specific Inductive Capacity " (S.I.C.) or dielectric constant and is denoted by the symbol K.

(The Specific Inductive Capacity of the dielectric path in a condenser has much the same effect as the permeability of the magnetic path has in an inductance.)

The S.I.C. of air is taken as unity, just as the permeability of air is taken as unity.

Approximate S.I.C. values of some dielectrics are :—

Air = 1 (greater when moisture is present, but otherwise fairly constant).
Ebonite = 2 — 3·2 (fairly constant).
Vulcanite fibre = 2·5.
Glass = 4 — 10 (Very variable. Pebble glass 5 (about). Plate glass 7 — 8.)
Shellac = 2·75 — 3·73.
Dry paper = 1·5.
Mica = 5.
Ice = 94.
Indiarubber = 2·12 — 2·34.
Porcelain 4·4 — 6·8.

There are many other dielectrics, of course, such as sealing-wax, paraffin-wax paper, &c., but they are little used in W/T.

Liquids :—

Distilled water has K = 83, but its efficiency is very low.
Paraffin = 2 — 2·3 (variable).
Finest vaseline oil = 2 (constant).
Service insulating oil = 2·217.
Petroleum and turpentine = 2·2.

**134. Capacity of a Parallel Plate Condenser.**—The capacity of a parallel plate condenser is—

(*a*) directly proportional to the area of dielectric under strain, *i.e.*, the area of one metallic plate multiplied by the number of sheets of dielectric. The latter is one less than the number of plates (*see* Fig. 50);

(*b*) directly proportional to the S.I.C. value;

(*c*) inversely proportional to the distance between the plates.

(1)

$$\text{C (in jars)} = \frac{\text{A} \times \text{K} \times \text{N}}{4000\pi \times \text{d}} \text{ where } \left\{ \begin{array}{l} \text{A = Area of one plate in } \textbf{square cms.} \\ \text{K = S.I.C. value.} \\ \text{N = No. of dielectrics under strain.} \\ \text{d = thickness of dielectric in } \textbf{cms.} \end{array} \right.$$

or (2)

$$\text{C (in jars)} = \frac{\text{AKN}}{5000 \text{ d}}$$ approx. where A and d are measured in **square inches** and **inches** respectively.

**Example 16.**

Find the capacity of a condenser of 16 tinfoil plates 15 cms. by 10 cms. separated by ebonite of S.I.C. = 2·5 and thickness ·2 mm.

$$N = 16 - 1 = 15 \text{ dielectrics under strain.}$$
$$A = 15 \times 10 \text{ sq. cm.}$$
$$C = \frac{15 \times 10 \times 2{\cdot}5 \times 15}{4000 \times 3{\cdot}14 \times {\cdot}2} = 2{\cdot}24 \text{ jars.}$$

**135.** Transmitting condensers are built up by cutting out tinfoil plates with tabs, thus (Fig. 49) :—

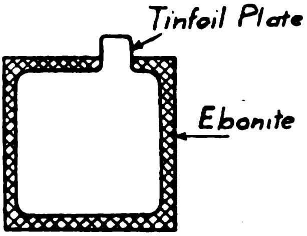


FIG. 49.

A simple way of building the condenser is then to put the plates alternately right and left-handed so that the plates can be connected in parallel, thus (Fig. 50) :—

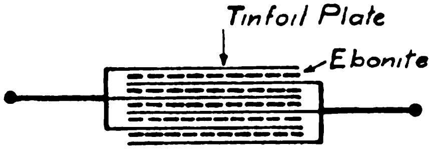


FIG. 50.

In the condenser illustrated in Fig. 50 there are—

6 sheets of tinfoil,
5 sheets of ebonite under strain.

An improvement in efficiency will result if a sheet of tinfoil is placed on **each side** of every ebonite sheet. When the whole condenser is compressed together, the adjacent sheets will be in good electrical contact, whereas if only one conducting plate be used there will probably be air gaps between a dielectric and the adjacent sheet of tinfoil, however evenly the pressure is applied.

It is a good plan to cut the dielectric rather larger than the conducting plates, as in Fig. 49, so that the tendency for sparking over between the edges of the plates will be minimised.

The corners of the plates should be rounded off, as in Fig. 49, as the electric charges on the plates are concentrated towards the corners, and this precaution will minimise the tendency to brush.

**136.** The condensers used in wireless telegraphy fall under three headings :—

(*a*) **Natural Capacity Circuits,** in which the capacity exists between the wires of the circuit itself, or between the circuit and earth.

(*b*) **Artificial Capacities,** in which a built-up condenser generally of the parallel plate type, is used.

(*c*) Combinations of (*a*) and (*b*).

(*a*) **Natural Capacity Circuits.**—Every ordinary electric circuit possesses capacity. In an electric cable the conductor forms one plate of the condenser, the insulation is the dielectric, and the outer lead casing, or the earth, the other plate.

In general, any two wires which are adjacent to each other have capacity to each other.

Thus, there is always a certain amount of capacity between the turns of a coil of wire. The combined effect of all the small capacities between turns is spoken of as the "**self-capacity**" of the coil.

Again, a suspended wire has a capacity to earth, the air being the dielectric.

The capacity of the wire is therefore very complex, being the sum of the capacities of each portion of it to the nearest earthed point as indicated in Fig. 51 (*a*).

This capacity may be increased by arranging wires to form a roof, as in Fig. 51 (*b*).

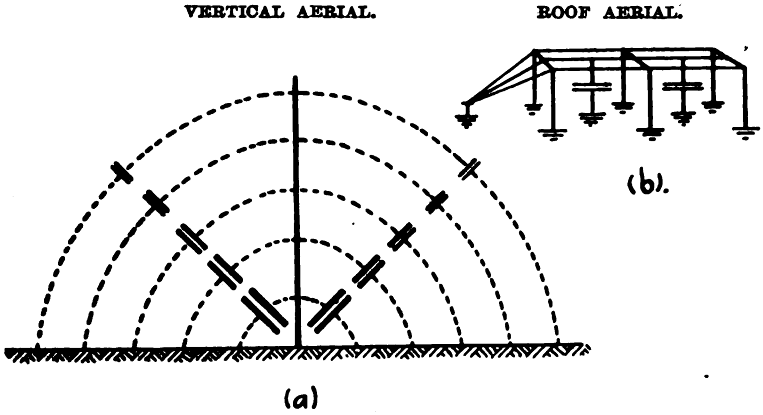


Fig. 51.

The total capacity is called the "**natural capacity**" of the wire to earth, and is denoted in the Service by the letter "$\sigma$" (sigma).

(*b*) **Artificial capacities.** These are used very extensively in wireless telegraphy, in transmitting, receiving, wavemeter circuits, &c. They will be dealt with in due course.

(*c*) In every circuit containing an artificial condenser, there must also always be a natural capacity to earth or between leads.

This capacity is in parallel with the artificial capacity and must therefore be added to it.

If the artificial condenser is large the capacity of the leads may be neglected, whereas if the condenser is small the latter may be a considerable factor.

If an artificial condenser be inserted in an earthed wire having a natural capacity to earth, it is in series with that capacity and reduces the total capacity value.

This will be referred to again later (para. **314**).

**137. Dielectric Strength.**—If the electric strain in a condenser rises beyond a certain point, the dielectric is punctured.

In the case of liquids or gases, the wound so created heals itself (though, in oil, contamination will occur), but in solids the insulation is punctured : *i.e.*, a hole is formed which only offers the insulation of air, instead of the insulation of the solid dielectric.

The voltage corresponding to that at which the rupture of a plate 1 mm. thick takes place is called the **dielectric strength** of the insulator.

A thin sheet of dielectric is **proportionally** stronger than a thicker one of the same material.

That is, a sheet of $\frac{1}{16}$in. thickness is not twice as strong as one of $\frac{1}{32}$in. but something considerably less.

For this reason, large condensers are usually built up of several different parts—or sections—connected in series : this saves space.

The strength of dielectrics is compared with that of air.

A spark of 1 mm. in air between flat metallic surfaces requires 4,300 volts. A spark of 2 mm. would only require 7,400 volts.

Two plates 2 cm. apart in air require 30,000 volts applied to spark across.

With spark balls the voltage is less, the less the diameter of the balls. Between sharp points the voltage required is much less.

The following are puncturing voltages for various dielectrics between plates 1 mm. ($\frac{1}{25}$in.) apart.

| Dielectric. | Puncturing Voltage. | Corresponding sparking distance between plates in air. |
|---|---|---|
| Crystal Glass | 28,500 volts. | 9 mm. |
| Indiarubber | 40,000 ,, | 13 mm. |
| Ebonite | 50,000 ,, | 14 mm. |
| Mica | 60,000 ,, | 20 mm. |
| (0·1 mm.) of mica | 10,000 ,, | 3 mm. |
| Oil (vaseline) | 6,000–8,000 volts. | 2·4 mm. |

It is usual in building condensers to allow a factor of safety of from 3 to 6 times the puncturing voltage, since the above only give voltages at which the dielectric is bound to puncture; it may puncture at a much less voltage if any brush discharge burns the plate or sparking takes place between the contacts.

**138. Dielectric Efficiency.**—Dielectric efficiency is the ratio of the energy output to the energy input, thereby taking account of any waste of energy that occurs during the charge and discharge of a condenser.

If a dielectric is perfect there should be no waste of energy in it.

In most condensers, however, this does not hold good, and there is a certain amount of energy absorbed, which is a waste loss in the dielectric.

The term " Hysteresis " is used to cover all these losses, and they may be summed up as :—

(*a*) **True resistance losses** in the plates. These are easily kept low in large parallel plate condensers.

(*b*) **Leakage** over the plate edges. To prevent this the condenser is immersed in oil in many cases and the plate edges are kept well away from one another and from the sides of the condenser tank.

(*c*) **Chemical action.**—This may take place if damp is present. Hence condenser cases must be properly sealed.

(*d*) **Conduction current** through the dielectric. This is obviously least when the insulation resistance of the dielectric is highest.

It would be quite large, for instance, if a partial conductor, such as wood, were used as a dielectric.

(*e*) A " soaking in " effect, whereby a condenser is not entirely discharged when it is short-circuited. If a condenser is charged, short-circuited, and then set aside for some time and again short-circuited, a small current will flow, showing that it did not entirely give up its charge on the first occasion.

For the last reason the value of K (dielectric constant) is not absolutely constant except at a fixed " frequency."

The value for direct current is as much as 10 per cent. more than for " low frequency " alternating current, and for " low frequency " alternating current as much as 5 per cent. more than for " high frequency " alternating current.

For " frequencies " above 300 cycles the value of K is practically constant.

The foregoing statement really means that the slower the condenser is charged, the more electricity can " soak " into the dielectric, and hence the more electricity the condenser can hold.

Air condensers have the highest efficiency; reckoning the efficiency of an air condenser as 100 per cent., other dielectrics have the following efficiency :—

Ebonite : 70 per cent. about (is more efficient for thick than thin plates : very much less efficient if ebonite is very thin).

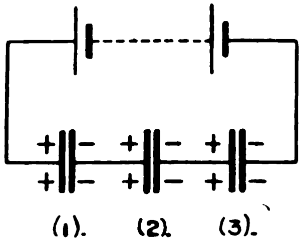
Glass : 60 per cent. (best plate glass may be more).

Mica : very variable. Good quality mica is now being made, having an efficiency as high as 90 per cent. Ordinary mica of older make may be as low as 40 per cent. Good mica is very expensive, and has to be made up in sheets clamped together to get efficiency as well as sufficient dielectric strength.

Oil : nearly 100 per cent., but only if it contains no moisture. If a can containing oil is left unsealed, it will readily absorb moisture from the atmosphere, and its efficiency will be impaired.

This moisture can be evaporated away by heating the oil—say by placing electric radiators on either side of the can. It is also very advisable to strain oil through a piece of chamois leather—placed fluffy side up—in order to remove any impurities from it.

### 139. Condensers in Series and Parallel.—



*Condensers in Series.*

FIG. 52(*a*).

(*a*) **Condensers in Series.**—If several condensers, $C_1$, $C_2$, $C_3$, &c. are joined **in series,** as in Fig. 52 (*a*), the combined capacity (C) of the three is such that—

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \&c.$$

This is proved in Chapter V., para. **231.**

If two condensers are joined in series, their joint capacity will be such that—

$$C = \frac{C_1 \times C_2}{C_1 + C_2}.$$

If several condensers of equal capacity are joined in series, their joint capacity can be found by dividing the capacity of one by the number joined in series.

Suppose three condensers are connected in series, and joined up to a battery, as shown in Fig. 52 (*a*).

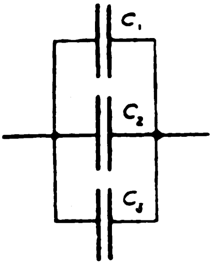
The left plate of No. 1 will be positive, being connected to the positive pole of the battery.

The field of this positive charge, acting through the dielectric, will attract all the free electrons in the conductors comprising the right plate of No. 1, the connecting wire, and the left plate of No. 2.

Similarly the free electrons between Nos. 2 and 3 will be repelled by the negative charge on the right plate of No. 3 and attracted by the positive charge on the left plate of No. 2.

Thus the distribution of electric charges will be as shown in the figure.

If the three condensers are of equal capacity, the potential difference across each will be equal, and will together be equal to the battery voltage.



*Condensers in Parallel.*

FIG. 52(*b*).

(*b*) **Condensers in Parallel.**—If several condensers are joined **in parallel,** Fig. 52 (*b*), the voltage across them will be the same, and the charges introduced will be :—

$$Q_1 = C_1V, \quad Q_2 = C_2V, \quad Q_3 = C_3V, \text{ \&c.}$$

Thus the total charge introduced will be such that

$$Q = Q_1 + Q_2 + Q_3 + \text{\&c.} = V\,(C_1 + C_2 + C_3 + \text{\&c.}).$$

Thus the joint capacity of several capacities joined in parallel can be obtained by adding their individual capacities together.

**Example 17.**

Find the joint capacity of two condensers of 3 jars and 5 jars, joined in series.

$$C = \frac{3 \times 5}{3 + 5} = \frac{15}{8} = 1\frac{7}{8} \text{ jars.}$$

**Example 18.**

Find the joint capacity of 5 condensers each 10 jars capacity, joined in series.

$$C = \frac{10}{5} = 2 \text{ jars.}$$

**Example 19.**

Find the joint capacity of 3 condensers, of 10 jars, 5 jars, and 1 jar, joined in parallel.

$$C = 10 + 5 + 1 = 16 \text{ jars.}$$

When the condensers are joined in parallel, the joint capacity of the combination is increased, and when they are joined in series, the joint capacity is less than that of the smallest one.

The advantage gained by joining condensers in series is an increase in dielectric strength (*see* Example 20).

For example, suppose the breakdown voltage of each of the units shown in Fig. 52 is 20,000 volts ; then arrangement (*a*) will only break down under a voltage of 60,000 volts, whereas arrangement (*b*) will only stand 20,000 volts before one or all puncture.

**140. Condensers used in Practice.—Transmitting Condensers for Spark Sets** have dielectrics of ebonite, mica or glass. Generally arranged several "sections" in series, to give adequate dielectric strength, and, if a variation of capacity is necessary, the sections are arranged in groups or "elements," whose terminals are brought out of the tank, so that by suitable switches these groups—termed "Elements"—may be arranged in various combinations.

The plates of ebonite or glass condensers are generally immersed in oil, to prevent brushing.

Fig. 53 (*a*) illustrates diagrammatically the construction of one element of a condenser and Fig. 53 (*b*) shows how the connections are actually arranged.

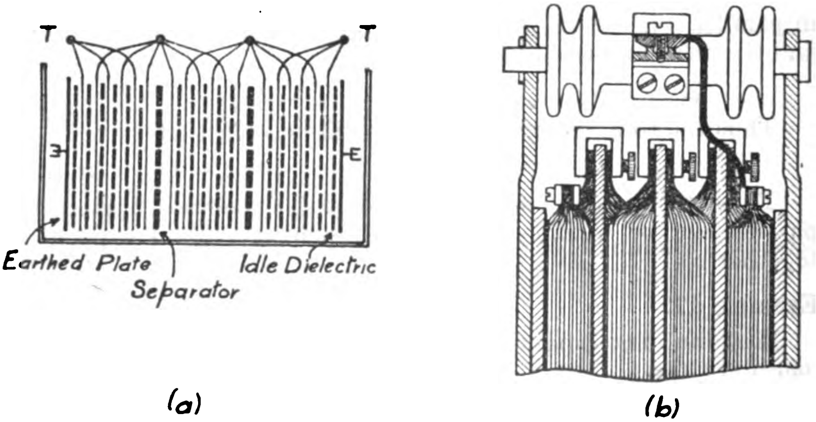


Fig. 53.

It can be seen that each section comprises, in the case illustrated, six active plates and five active dielectrics under strain.

Between sections are placed ebonite separators generally of thicker material.

The whole element is clamped up between metal plates, which are earthed.

Next the active plate at each end is placed a sheet of dielectric, and next it a conducting plate in electrical connection with the earthed clamping plate, so as to keep the capacity to earth constant.

An example of an arrangement of several elements to give a variation of capacity is illustrated in Fig. 54 (*a*).

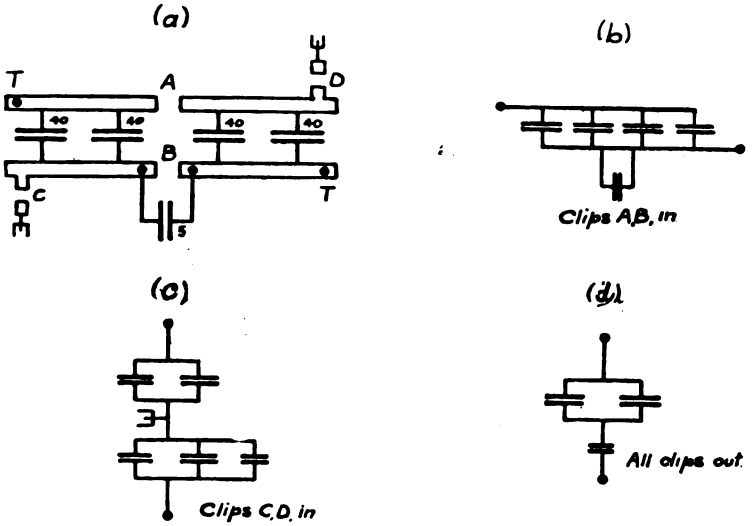


Fig. 54.

The condenser illustrated consists of four elements of 40 jars each (made up of four sections of 160 jars each in series), permanently connected as two pairs in parallel (80 jars each). The terminals of the condenser are shown (T, T).

Joined across the condenser is another one of capacity 5 jars.

Clips can be put in at A, B, or C, D.

Fig. 54 (*b*), clips A, B in. Here the two pairs of elements (80 jars each) are arranged in parallel: total capacity :—

$$= 2 \times 80 = 160 \text{ jars.}$$

Fig. 54 (*c*) clips C, D in. Here we have the two pairs in series with their centre point earthed, and a condenser of 5 jars joined in parallel with one pair.

Thus we have a condenser of 80 jars in series with one of 85 jars.

$$\text{Total capacity} = \frac{80 \times 85}{80 + 85} = \frac{6800}{165} = 41 \cdot 2 \text{ jars.}$$

Fig. 54 (*d*) all clips out. Here we have one pair (80 jars) in series with the 5 jar condenser.

$$\text{Total capacity} = \frac{80 \times 5}{80 + 5} = \frac{400}{85} = 4 \cdot 7 \text{ jars.}$$

**Example 20.**

You have the following materials available: ebonite $\frac{1}{32}$ in. thick (S.I.C. = 2·5) and dielectric strength sufficient to stand 5,000 volts, and tinfoil sheets 12 in. × 12 in.

You wish to construct a condenser (*a*) to give a total capacity of 234 jars with its elements arranged in parallel, and (*b*) to stand 15,000 volts with its elements arranged in series.

(i) How many plates would you require for (*a*) and (ii) what would be the capacity of the condenser in (*b*).

For (*b*) we shall require three elements in series to stand 15,000 volts.

Hence capacity of each element, to give 234 jars when the three are joined in parallel will be :—

$$\frac{234}{3} = 78 \text{ jars.}$$

$C = \frac{AKN}{5000d}$. Hence N (the number of dielectrics required) will be equal to $\frac{C \times 5000 \times d}{AK}$

$= \frac{78 \times 5000}{12 \times 12 \times 2 \cdot 5} \times \frac{1}{32} = \frac{390,000}{11,520} = 33 \cdot 8 = 34$ dielectrics.

Hence the number of plates required for each element $= 34 + 1 = 35$.

Total number of plates $= 3 \times 35 = 105$ plates.

(ii) The capacity of three elements of 78 jars joined in series will be $\frac{78}{3} = 26$ jars.

**141. Receiving Condensers.**—Receiving condensers are designed to have a maximum dielectric efficiency, and to occupy a minimum of space.

Mica or air dielectrics are used—mica where the required capacity is fairly large, and air where the required capacity is small, and great efficiency is desired.

A common type of variable capacity condenser is illustrated in Fig. 55.

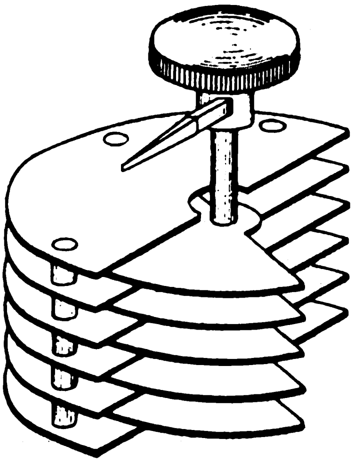


FIG. 55.

This condenser consists of a series of metal plates cut in the form of semi-circular segments.

The odd-numbered ones are mounted one above the other at equal fixed intervals, attached to a rigid support, while the even-numbered ones are mounted in a similar manner on a rotating pivot.

These latter plates can then be introduced into the interstices between the fixed plates so as to overlap them more or less.

The greater the overlap the greater the capacity.

The amount of overlap is measured by a pointer travelling over a scale of degrees.

If it is desired to increase the capacity of this condenser, it may be immersed in oil, for the reason that the S.I.C. of oil is higher than that of air.

## CHAPTER IV.

## ELECTRIC GENERATORS AND MOTORS.

**142. Electric Generators or Dynamos** are machines which, by utilising the principle of magnetic induction, convert mechanical energy into electrical energy. The mechanical turning of the rotating portion of the generator causes conducting coils associated with the machine to be interlinked by a magnetic flux. This flux is usually produced by electromagnets. The linking of the flux induces an E.M.F. in the conductors. Now, if this E.M.F. be impressed on a closed conducting circuit it will force through this circuit an electric current—*i.e.*, a transference of electrons occurs.

Dynamos can be classified broadly under two headings, namely, Alternating Current Machines, commonly known as **Alternators,** and **Continuous Current Machines.** The principles underlying both are the same, but the method of applying these principles in the design of the machine varies according to the results required.

**143. The Alternator.**—Fig. 56 (*a*) shows a conducting loop arranged in a magnetic field, with a collector ring electrically connected to each side of the loop and provided with two metallic brushes, each so mounted as to make electrical contact with one of the collector rings.

The external circuit is connected to the two brushes as shown.

Call the conductor on one side of the loop A, and that on the other side B.

In Fig. 56 (*b*), (*c*), (*d*), and (*e*) the loop is shown in section at successive positions, at angles of 0°, 30°, 60°, and 90° with the vertical.

Now consider the changes in flux enclosed by the coil. In Fig. 56 (*b*) the coil is enclosing 19 lines; in Fig. 56 (*c*) 15 lines, a decrease of 4 lines; in Fig. 56 (*d*) 8 lines, a decrease of 7 lines; and in Fig. 56 (*e*) no lines, a decrease of 8 lines.

It is not possible in a figure such as this to draw sufficient lines to get any accurate results, but at any rate we may deduce that when the loop is moved a very small way away from the vertical position the decrease in flux interlinked by the coil is small, while the nearer the coil gets to the mid position between the poles the more rapid is the decrease in the flux enclosed.

After the mid position has been passed, the flux enclosed by the coil increases, at first rapidly and then more and more slowly, till the vertical position is reached once more.

Now the magnitude of the E.M.F. induced in the coil depends upon the rate of change of flux enclosed by the coil.

Hence, when the coil is moving from 0° to 90° the E.M.F. induced will increase from zero to maximum, and when moving through the next quadrant it will fall from maximum to zero.

**144.** As regards the **direction** of the induced E.M.F. one need only apply Fleming's right-hand rule (para, **100**). The bar A is cutting lines of force in an upward direction and the field is from left to right; hence the direction of the E.M.F. will be **in**.

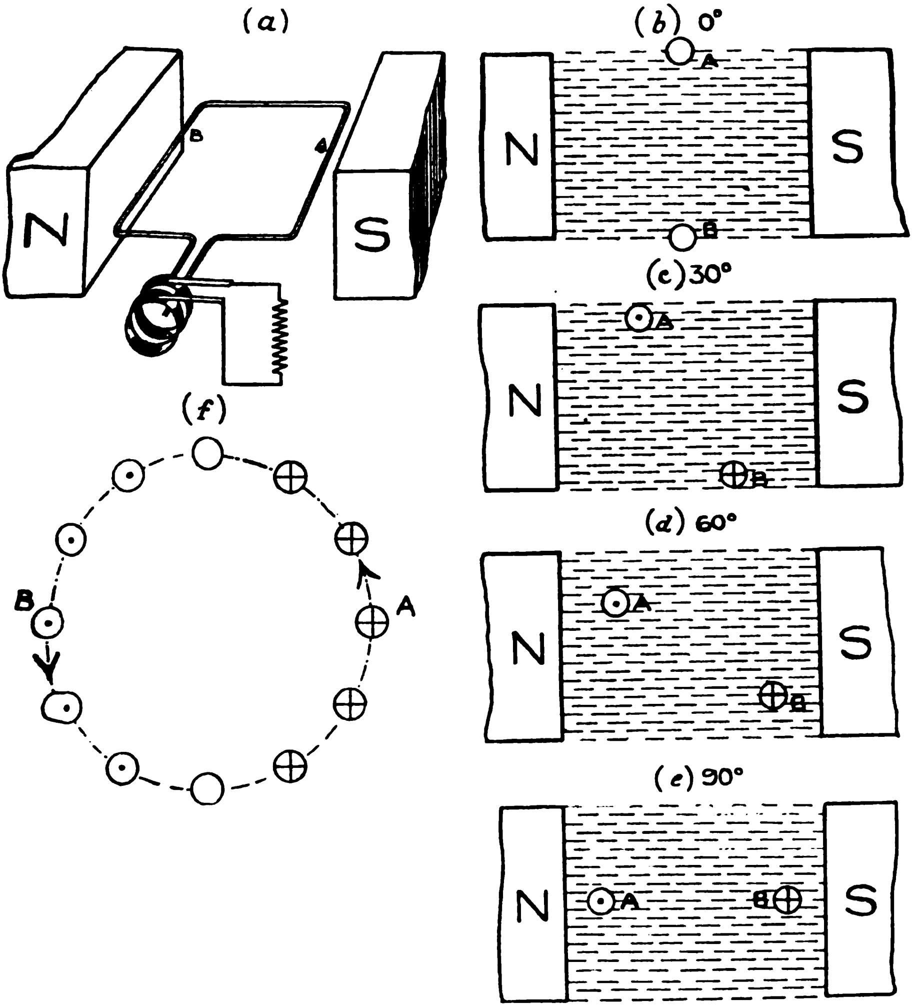


Fig. 56.

The bar B is cutting the same field in a downward direction; hence the direction of the induced E.M.F. will be **out**.

Thus the induced E.M.F.s in the two bars will combine to drive a current round the circuit.

The total E.M.F. acting round the loop will be double that generated in either bar.

When the loop has turned through half a revolution, and conductor B begins to move up on the right, and A down on the left, the directions of the E.M.F.s in the two bars will be reversed.

Fig. 56 (*f*) illustrates the directions of the E.M.F.s at successive instants.

Hence the E.M.F. induced in any one armature bar A varies from a maximum in one direction when the bar is opposite the centre of one pole, to zero when it is on the **neutral line**—midway between the poles.

Then the direction of the E.M.F. reverses, and rises to a maximum in the opposite direction, and falls to zero once more.

**145. The Sine Curve.**—It is required to show that the voltage induced in any loop, rotating at a uniform speed in a uniform field, varies as the sine of the angle through which the loop has been turned, from the neutral plane which lies at right angles to the field.

The loop AB is being rotated in the uniform field shown in Fig. 57.

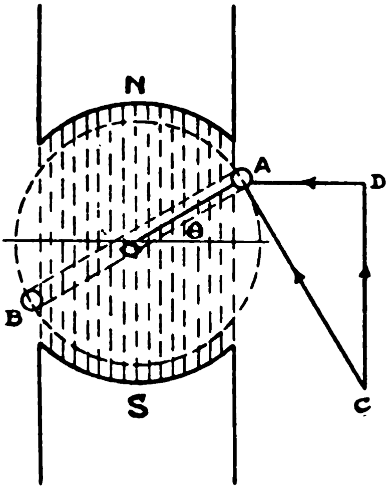


FIG. 57.

The line AC drawn at right angles to OA (that is, as a tangent to the circular path in which A and B are revolving) will represent the direction of motion of the conductor at the instant shown after it has revolved through an angle $\theta$.

Its length, drawn to any convenient scale, can be taken to represent the constant angular velocity of the bar A.

We will draw the line AD horizontally from the point A, and the line CD vertically from the point C.

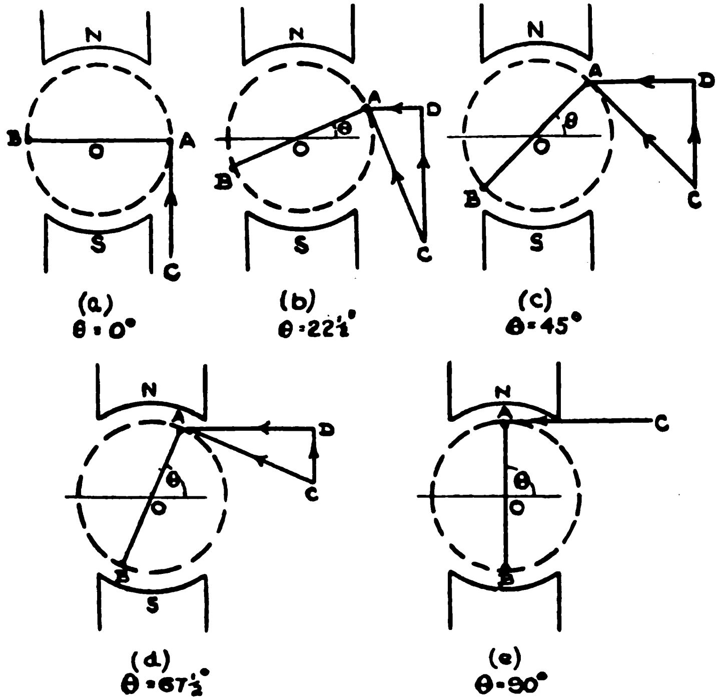
We have now got a triangle of velocities (Appendix A p. 503). The velocity line CA has been resolved into two components, viz., AD representing the horizontal velocity of the bar A, and DC representing its vertical velocity.

From the point of view of generating E.M.F. we are only interested in the horizontal movement of A, since it is only when moving horizontally that it cuts across the magnetic field, and generates an E.M.F.

The length of AD at any instant will, therefore, be a measure of the rate of cutting of lines of force by A, and therefore of the voltage generated.

The vertical component CD represents the motion of A parallel to the field, which motion has no effect in generating an E.M.F.

We therefore wish to investigate how AD will vary during a revolution of the bar A.



(a) $\theta = 0°$

(b) $\theta = 22\frac{1}{2}°$

(c) $\theta = 45°$

(d) $\theta = 67\frac{1}{2}°$

(e) $\theta = 90°$

FIG. 58.

**146.** Fig. 58 shows the bar in successive positions as the angle $\theta$ varies from 0° to 90°.

(*a*) $\theta = 0°$, $DC = AC$, and $AD = 0$; no lines of force are being cut and no voltage is being generated.

(*b*), (*c*), (*d*). The line AD, and therefore the voltage generated, steadily increases.

(*e*) $\theta = 90°$: AD = AC: therefore the voltage generated is a maximum,
and so on.

Now $\frac{AD}{AC}$ = sine of the angle ACD.

Therefore AD = AC × sin ACD = a constant × sin ACD.

It is obvious from Fig. 58, and can easily be proved, that the angle ACD = the angle $\theta$.

Therefore AD = a constant × sin $\theta$.

Now AD is proportional to v, the voltage induced at any instant: if $V_m$ is the voltage when A is opposite the centre of either pole, we see that v will be a certain fraction of $V_m$ depending on the angle $\theta$ through which the loop has revolved.

**That is $v = V_m \sin \theta$.** (1)

Taking figures, let us suppose that $V_m$ is 10 volts.

Then from the table of sines on p. 536, we find that v will go through the following values :—

| $\theta$ | 0°, | 10°, | 20°, | 30°, | 40°, | 50°, | 60°, |
|---|---|---|---|---|---|---|---|
| v | 0, | 1·74, | 3·5, | 5·2, | 7, | 7·6, | 8·6, |

| $\theta$ | 70°, | 80°, | 90°, | 100°, | 110°, | 120°, etc. |
|---|---|---|---|---|---|---|
| v | 9·4, | 9·8, | 10, | 9·8, | 9·4, | 8·6. |

A convenient method of plotting the curve $v = V_m \sin \theta$ geometrically is shown in Fig. 59.

Let the line OA represent $V_m$. Then the line AM = OA sin $\theta$.

We may now take a horizontal line DE to represent degrees and plot on it the various lengths and directions of the line AM as the point A revolves.

Fig. 59 is a graph of the various values of AM as the line OP revolves through 360°. The dotted lines indicate how the curve is constructed, and should need no further explanation.

When AM comes above the line CD we call it positive in sign. This will be for values of $\theta$ lying between 0° and 180°. For values of $\theta$ between 180° and 360° A will be below the line and AM will be negative.

After joining up all the points we have the curve as in Fig. 59.

A curve constructed in this manner is termed a "**Sine Curve.**"

The maximum height of the curve, called its "**amplitude,**" will be equal to OA, which equals $V_m$.

At all times the height of the curve $= V_m \sin \theta$, so that—

When $\theta = 0°$ or $180°$, $V_m \sin \theta = 0$: when $\theta = 90°$ or $270°$, $V_m \sin \theta = V_m \times 1 = V_m$.

The variation of the curve from zero, to a maximum positive, to zero to maximum negative, and back to zero again, is termed a "**Cycle.**"

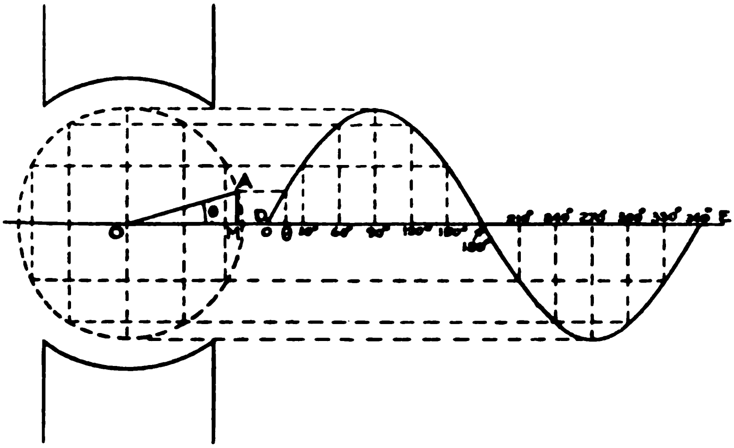


Fig. 59.

**147. Frequency.**—In every revolution of the armature bar, the cycle of the E.M.F. is gone through.

Hence, if the bar is revolving at f revolutions per second, f cycles are gone through per second.

"**Cycles per second**" is termed "**Frequency.**"

In the two-pole machines shown, the frequency = revolutions per second.

If the alternator has more than one pair of poles (as indicated in Fig. 60), then a cycle occurs for each pair of poles passed in the course of the revolution.

Hence, **Frequency = revs. per sec. × number of pairs of poles.**

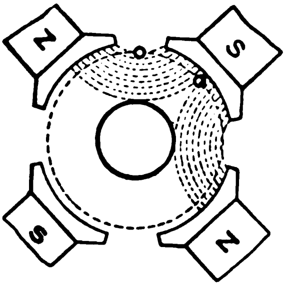


Fig. 60.

**148.** Now it will be convenient to express the angle $\theta$ in **circular measure** (*see* Appendix A, p. 490).

It is found as follows:—

In one second f revolutions take place, each of 360° for a two pole machine: but 360° $= 2\pi$ radians.

Therefore in one second f revolutions take place, each of $2\pi$ radians.

In one second $2\pi f$ radians are "swept" out in all.

So $2\pi f$ is the number of radians swept out per second.

This is called the "**angular velocity.**"

To save writing, the expression $2\pi f$ is denoted by the letter "$\omega$" ( a Greek letter called "omega").

Thus $\omega = 2\pi f = 6{\cdot}28 \times f$.

Formula (1) on page 91 thus becomes

$$v = V_m \sin \omega t \text{ volts} \qquad (2)$$

If two pairs of poles are fitted, although the armature sweeps out only 360 actual degrees, we have two complete cycles, which require on the curve 720 electrical degrees.

By using "$\omega$" to represent angular velocity, we mean "electrical" angles, without any reference to any definite number of poles.

**149. Alternating Current.**—Now let us take this sinusoidal voltage and apply it to the ends of a circuit, shown in Fig. 56 (*a*).

Suppose, at first, that the circuit contains resistance, but that it is non-inductively wound and has no capacity.

A current will flow, which will rise, fall and reverse in step with the voltage impressed on the ends of the circuit, and we can employ Ohm's Law to find the strength of the current.

Hence, the current at any moment $= \dfrac{V}{R} \sin \omega t = I_m \sin \omega t$.

**150. The Alternator.**—A single armature bar would have to be revolved at a tremendous speed in a very dense magnetic field in order to generate an E.M.F. that would be of any use to us.

An alternator armature winding therefore consists of several groups of windings arranged in series, separated by the same distance that separates the poles, and so wound that the E.M.F.'s induced in all the coils act in the same direction, as in Fig. 61.

In Fig. 62 is illustrated a portion of an armature winding in successive positions as it passes under a pair of poles.

When it starts (*a*) it is not cutting any field, and so is generating no E.M.F.

Then as it moves under the pole pieces, the E.M.F. induced in it rises, till in Fig. (*c*) it is generating a maximum E.M.F. (as shown by the curve above it) because it is cutting across the field at right angles.

Then as it moves away from the central position the generated E.M.F. will fall off, till it is zero again as in Fig. (*e*).

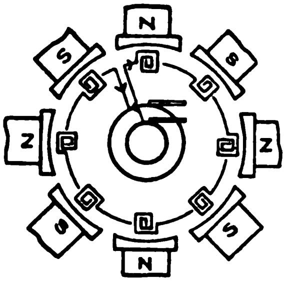


**Fig. 61.**

The right hand side of the coil will then come under the influence of the north pole and the left hand side under that of

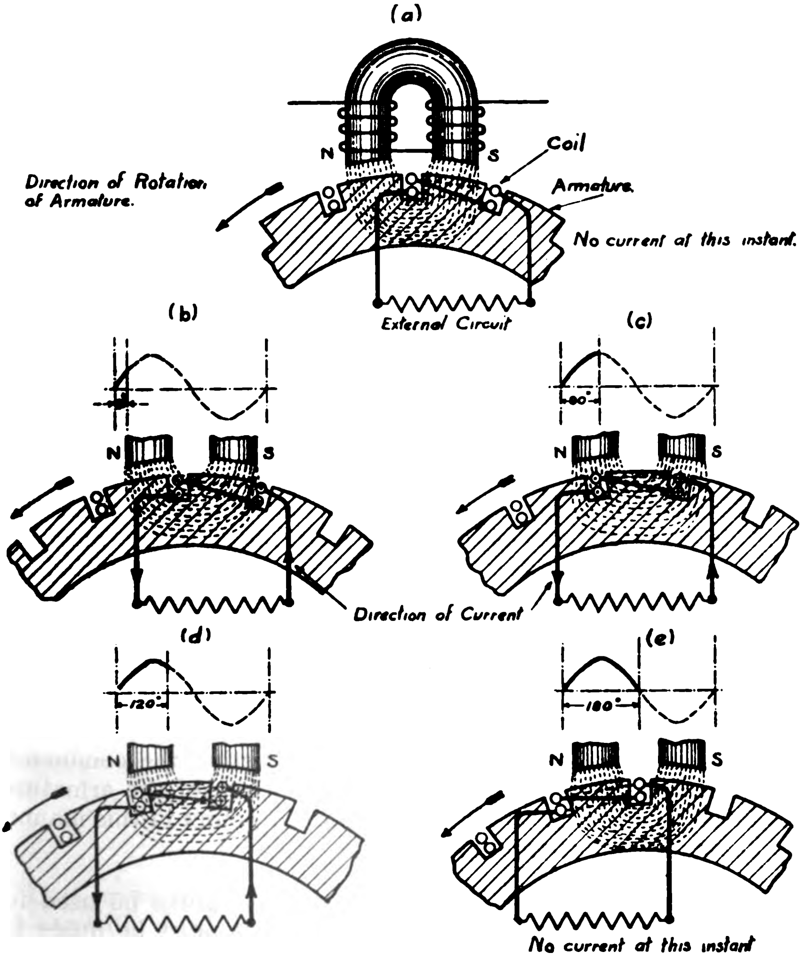

(a)
N
S
Coil
Armature.
Direction of Rotation of Armature.
No current at this instant.
External Circuit
(b)
N
S
(c)
60°
N
S
Direction of Current
(d)
120°
N
S
(e)
180°
N
S
No current at this instant

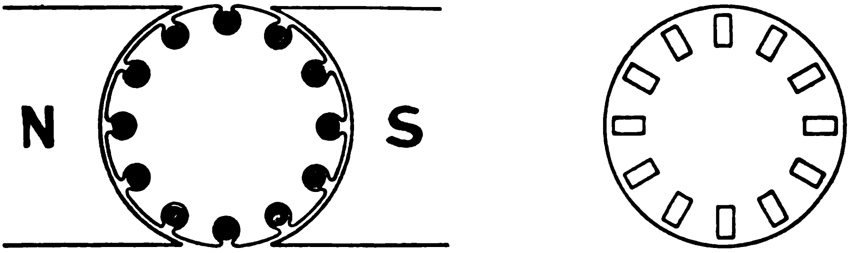
**Fig. 62.**

the next south pole (not shown in the illustration) and the E.M.F. will start to rise in the opposite direction.

**151. The Armature.**—We have previously shown that for a given magnetising force the total number of magnetic lines produced in a magnet will depend upon the reluctance of the magnetic circuit. The greater part of the reluctance in a magnetic circuit of ordinary dimensions is due to the air gap. It is clear, therefore, that, by reducing the air gap between the poles, we can get a greater density and therefore a greater total number of magnetic lines with the same magnetising force.

This air gap can be reduced in two ways, firstly by shaping the pole faces in a curve so that they are parallel to the path of rotation of the conductors, and secondly, by filling up the space inside the path of the conductors—that is to say, filling up the core of the armature—with iron.

Such an arrangement is shown in Fig. 63 (*a*), where, as is usual in most dynamos, the conductors are shown embedded in slots in the iron core, thus reducing the gap between the iron of the pole face and the iron of the armature core to a minimum.



*Armatures.*

(*a*) *Slotted.* (*b*) *Tunnel.*

Fig. 63.

Besides increasing the density of the magnetic field, this will, to a certain extent, alter the distribution of the magnetic lines of force, with the result that the E.M.F. generated by rotating the conductor through a complete revolution will not exactly follow the sine curve as shown in Fig. 59.

Alternators designed for wireless telegraphy purposes, however, are generally arranged to give what is practically a sinusoidal voltage curve.

This is sometimes arranged for by inserting the conductors through holes completely enclosed by the iron of the armature, as illustrated in Fig. 63 (*b*). An armature wound in this manner is known as **tunnel-wound.**

**152. Pole winding.**—Unless permanent magnets be used for the field of an alternator, some arrangement must be made for producing a magnetic flux through the pole pieces.

Except for special machines (such as a "magneto") permanent magnets are unsuitable; in the first place the magnetic flux density is low, thereby necessitating a large amount of steel to produce a given amount of flux; secondly, any current taken from the armature tends to demagnetise the poles owing to reaction; and thirdly, they are expensive.

It is usual, therefore, to use **electro-magnets** for the fields of a dynamo, *i.e.*, coils of wire wound round cores, and supplied with direct current as illustrated in Fig. 64.

In order to regulate the current flowing through the field winding, an adjustable resistance is inserted in series with the mains, termed a "Field Regulator."

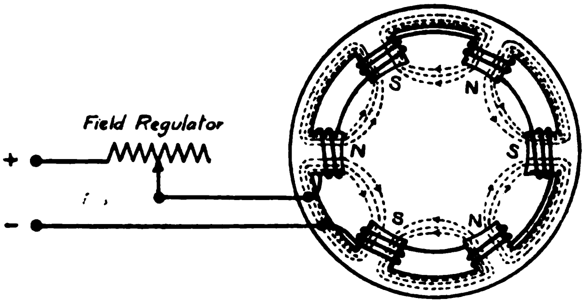
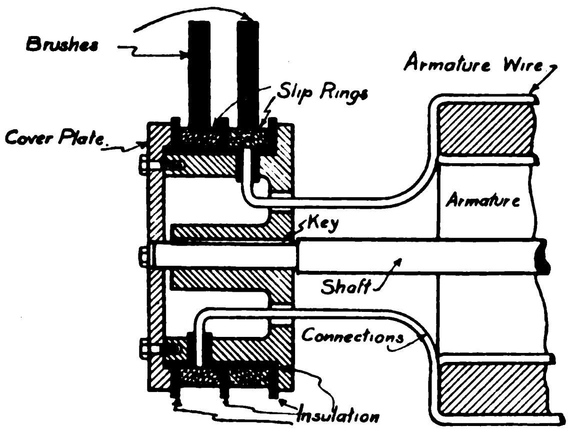


Fig. 64.

**153. The Slip Rings.**—Since the armature of the type of machine being described must necessarily be kept revolving to generate an E.M.F. a method must be devised for connecting the windings of the armature to any desired outside circuit.

This is usually accomplished by what are known as "**slip rings**" and "**brushes.**"



*Slip Rings.*

Fig. 65.

Two brass rings are carried on the shaft of the armature and carefully insulated from each other and from the shaft as shown in Fig. 65.

These rings rotate with the armature, but as they have a smooth surface, connection can conveniently be made to them from a fixed part of the machine by means of carbon " brushes " pressing lightly on the surface of the rings.

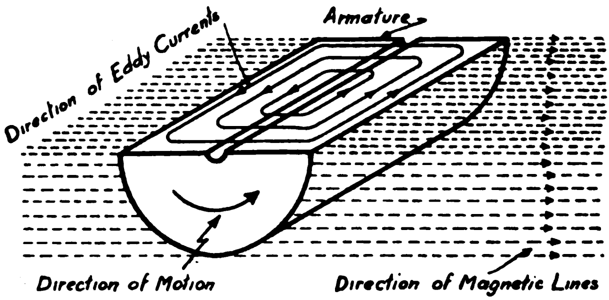
One end of the armature winding is then connected to one slip ring and the other end to the other slip ring, while the outside circuit to which it is desired to connect the dynamo is connected to the two brushes.

**154. Eddy Currents.**—We have already shown how the conductors of the armature are embedded in an iron core in order to reduce the air gap in the magnetic circuit of the alternator.

Obviously, this iron core revolves with the conductors in the magnetic field. Since the iron is also a conductor of electricity and is also unavoidably cutting the lines of force induced by the field magnets, the result is that E.M.F.s are generated in the iron body of the armature which cause currents to circulate continually in the metal.

These currents are known as **Eddy Currents,** and since they cannot be utilised they only represent so much wasted energy, and in addition heat up the iron of the armature core to the detriment of the running of the machine. Means must therefore be found of reducing them to a minimum.

The direction of these currents will be found by applying Fleming's " Right Hand Rule," and will be as shown in Fig. 66, that is to say, round the core at right angles to the lines of force.



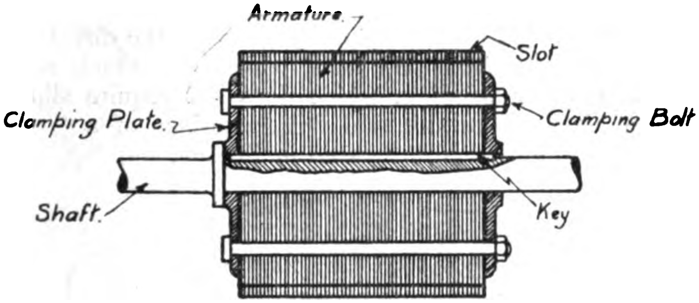
*Eddy Currents in Armature.*

Fig. 66.

**155. Lamination.**—To prevent these currents flowing, armature cores are built up of a large number of thin circular plates of iron separated from one another by very thin paper or varnish. The plates are threaded on to the armature shaft and are clamped together by some suitable means, such as that illustrated in section in Fig. 67.

It will be seen that these sheets of paper, being non-conductive, offer a large resistance to any currents which tend to flow in the iron core in a direction parallel to the shaft, as indicated in Fig. 66.

At the same time they do not increase the reluctance of the magnetic circuit to any great extent as the lines of force can pass freely down each plate of the armature core without passing through the paper.



*Lamination of Armature.*

FIG. 67.

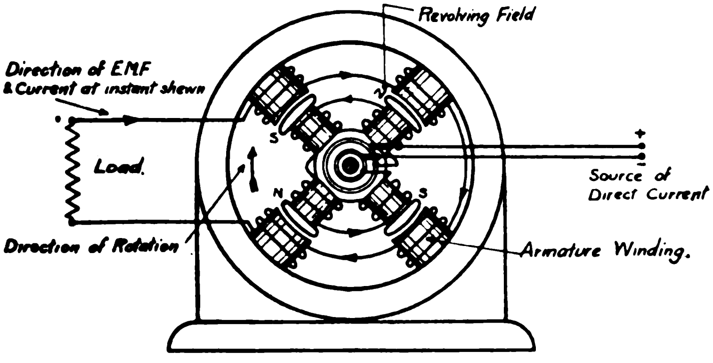
**156. Alternator Construction.**—Practical alternating current generators may be divided into three classes, thus :—

(1) Revolving armature machines.
(2) Revolving field machines.
(3) Inductor-type machines.

**157.**—(1) **Revolving Armature Machines.**—These are of the type previously described, and are spoken of as having a "Rotor" (or revolving) armature, and a "Stator" (or stationary) field.

A revolving armature carries the winding in which the alternating current is generated, and poles projecting inwards from a yoke in the form of a ring carry the field windings, which are supplied with direct current from an outside source.

(2) **Revolving Field Machines** (Fig. 68).—These have a Rotor field and a Stator armature, *i.e.*, the magnet coils are carried on poles projecting from a hub (or ring in larger sizes) and are supplied with direct current through two slip rings, while the

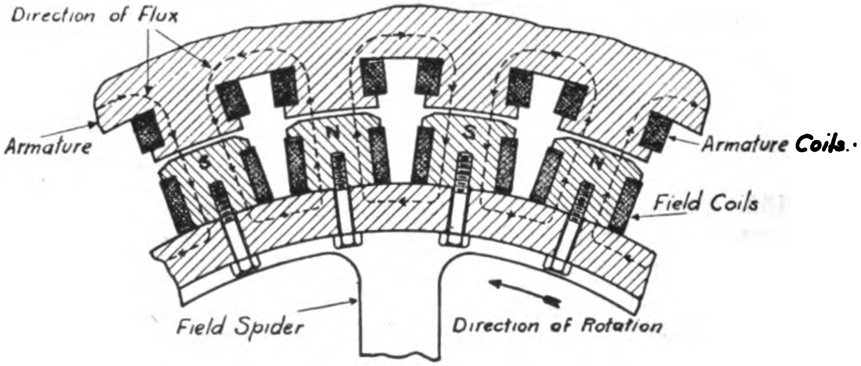


*Alternator. Rotor Field Type.*

FIG. 68.

armature winding in which the alternating current is generated is wound on projections on the inside of a cylinder enclosing the rotor.

This is a more convenient method of generating a high voltage alternating current since the conductors and slip rings of the rotor have to stand only the voltage of the direct current supplied for magnetising the field, while it is much easier to insulate the stator winding, which does not require slip rings. A portion of the armature and field windings of a "rotating field" type of winding is illustrated in Fig. 69.



*Rotor Field—Constructional Details.*

FIG. 69.

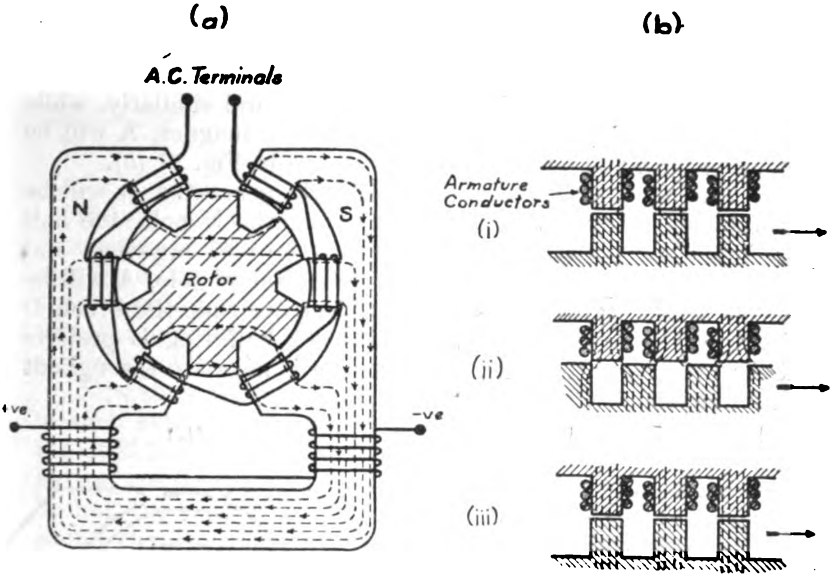
**158.—(3) The Inductor Type.**—In the "Inductor" type of alternator, both the armature winding and the field magnet winding are wound on projections inside the stator, while the rotor consists of a drum carrying projections of steel or iron material.

Fig. 70 (*a*) illustrates diagrammatically a machine of this type. The armature winding is wound on projections of the stator, while, for clearness, the field winding is shown on the legs of the field magnet system. The rotor is simply a soft iron cylinder with projections whose width corresponds to the pole pitch of the stator.

Fig. 70 (*b*) illustrates this action. The flux is formed into "tufts" each time a rotor pole is opposite a stator pole ( (i) and (iii) ): when the poles are in the midway position (ii) the flux is fairly evenly distributed across the air gap. Therefore, considering any one stator pole, the flux is continually spreading out and gathering in again, the spreading out causing one alternation and the gathering in a reverse alternation, the two together forming one complete cycle.

A P.D. is developed in the stator winding and is in the form of a sine curve.

The frequency is given by the number of revolutions per second of the rotor multiplied by the number of its projections.



*Alternator—Inductor Type—diagrammatic.*

Fig. 70.

## THE DIRECT CURRENT GENERATOR, OR DYNAMO.

**159.** Exactly the same principles hold good as regards the E.M.F.s produced in the conductors of the armature of a continuous current dynamo. That is to say, alternating E.M.F.s are produced in the conductors themselves, but, as we shall show later, these alternating E.M.F.s, instead of being brought straight to the outside circuit through slip rings as in the case of the alternator, are taken through an apparatus for automatically reversing their direction, so far as the **outside** circuit is concerned, at definite intervals.

In order to produce a continuous current in the outside circuit, or, as it may be better considered, in order to produce a continuous E.M.F. at the brushes of the dynamo, an arrangement is provided for reversing the connections of the armature coils at the brushes at the moment when the E.M.F. induced in the coils reverses.

This arrangement is known as the **Commutator,** and its action is described in the following paragraphs.

**160. The Commutator.**—Let us take the simplest case of a single coil being rotated, as shown in Fig. 71.

If the two ends of the coil, instead of being connected to two slip rings, be connected one to each half, A and B, of a divided ring which rotates with the armature, and if the two brushes C and D be fixed in the position shown, it is evident that while the coil is travelling under the N pole of the magnet the half ring A will be in contact with the brush D and the half ring B with the brush C (Fig. 71 (*a*) ), and similarly, while the coil is travelling under the S pole of the magnet, A will be in contact with C, and B with D, as shown in Fig. 71 (*b*).

By tracing the directions of the E.M.F. generated, it will be seen that while the coil is travelling under the N pole, the half ring A will be positive and B will therefore be negative, and similarly while the coil is travelling under the S pole, A will be negative and B positive. It follows therefore that the brush D will always be in contact with whichever half ring is positive and the brush C with whichever half ring is negative throughout the revolution.

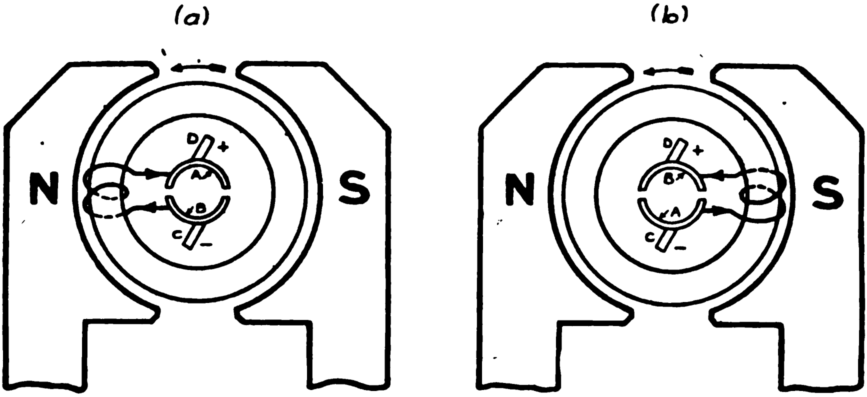


Fig. 71.

Since the wave form of the E.M.F. generated in the active conductors of the coil takes the form shown in Fig. 59 it is obvious that the curve showing the value of the E.M.F. at the brushes, when the coil is thus connected to a split ring, will take the form shown in Fig. 72.

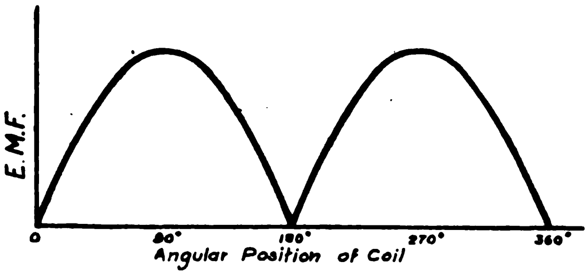


Fig. 72.

Let us develop this arrangement a little further, and take a commutator with four segments, connected to four points on the armature winding, as in Fig. 73.

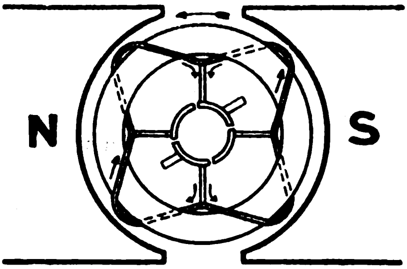


Fig. 73.

If now we adjust the position of the brushes so that they commence to make connection with a commutator segment ⅛th of a cycle, or 45 degrees, before the E.M.F. in these segments is at its maximum, as indicated in Fig. 73, we shall get four unidirectional impulses of E.M.F. applied to the brushes in each revolution.

Now since the armature is continuous throughout, the E.M.F. in each half (*i.e.* on each side of the brushes) will be the sum of the E.M.F.s in each conductor of that half; and since the two halves are feeding the brushes in parallel, the total E.M.F. will be half the sum of the instantaneous voltages in each conductor round the armature, or, the sum of the voltages in one half of the armature winding. This fact is indicated by the heavy line curve in Fig. 74.

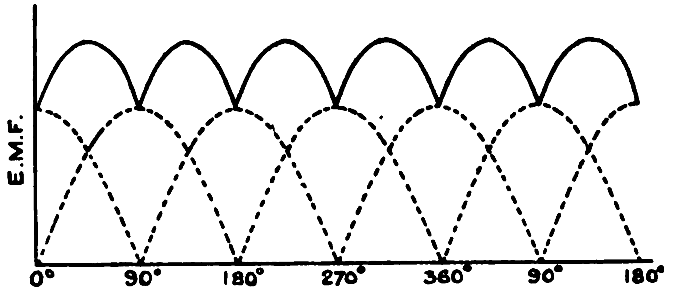


Fig. 74.

**161. Armature Windings.**—In practice, an armature winding consists of a great many conductors arranged in slots on an iron core. Each conductor is connected to one segment of the commutator.

The conductors are not in practice arranged as in Fig. 73, which illustrates a "ring wound" armature, but are wound entirely on the outside of the armature, as in Fig. 75.

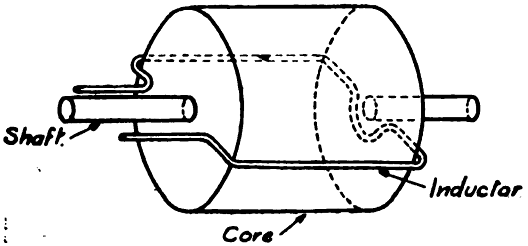


Fig. 75.

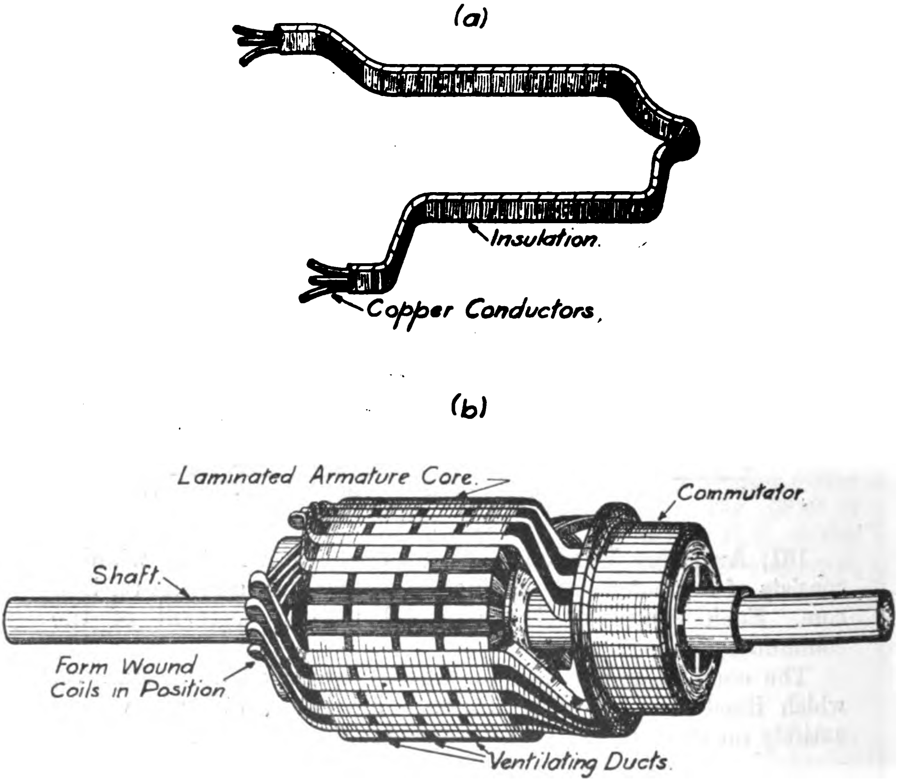
All the coils are so arranged that they, together with the commutator segments to which they are connected, form a closed circuit upon themselves, and each coil always comprises part of the circuit; consequently the P.D. between the brushes is half the sum of the average E.M.F.s induced in all the conductors.

An illustration of one coil, and the way coils are built up on an armature, is given in Fig. 76 (*a*) and (*b*).

There are two main types of windings—

(1) Lap (or parallel), and (2) Wave (or series), with simple and complex forms of each.

The reader is referred to any standard electrical text book for a description of the various methods of winding an armature.



*Armature Winding.*

FIG. 76.

**162. Load on the Dynamo Engine.**—The dynamo is rotated mechanically either by a steam engine or by an electric motor.

Now, the greater the current taken from the dynamo the greater will be the load thrown on the engine, for the following reasons:—

If the armature shown in Fig. 77 is revolving in a clockwise direction, the current induced in the armature bars will tend to **magnetise the armature** as shown, *i.e.*, so as to produce a S pole on top and a N pole below.

Now the S pole of the armature will be repelled by the S pole of the field, and the N pole of the armature by the N pole of the field, and so the armature, when a current is flowing round it, resists the turning efforts of the steam engine.

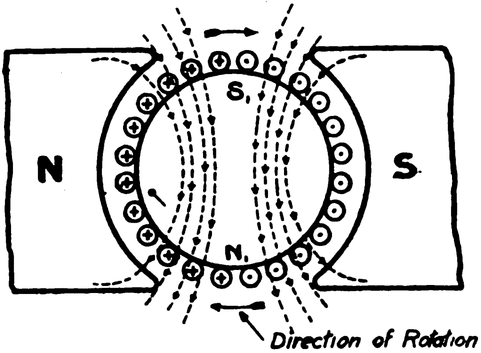


FIG. 77.

Obviously, the more current is being taken from the dynamo the stronger is this action, and consequently the more expenditure of energy is required on the part of the turning engine.

If the dynamo is delivering $I^2R$ watts to the outside circuit, the turning engine will have to supply $\frac{I^2R}{746}$ h.p. (746 watts = 1 h.p.) without considering frictional losses, &c.

**163. Armature Reaction** is the magnetic influence produced by the current in the armature of a generator or motor under load, on the magnetic circuit of the machine; it is the cause of what is termed field distortion.

It occurs as follows:—

When the machine is on load, the current flowing through the armature winding will tend to magnetise the armature as shown in Fig. 77.

There are thus two fields acting on the armature; one, due to the field-coil current, has a direction straight across between the poles; the other, due to current in the armature inductors, has a direction at right angles to the first. The effects of these two fields are simultaneous and superimposed. They combine to produce a distorted field as shown in Fig. 78. The flux across the air gap in the pole pieces and armature core is now no longer uniform, but becomes dense towards the toes of the pole shoes in the direction of rotation.

Furthermore, the neutral line is shifted round through some angle, in the direction of rotation.

As the armature current—or "load"—increases this distortion will increase.

One result of this armature reaction is that the brushes must be given "lead"—or an advance in the direction of rotation—so as to have them on the neutral line, the amount of lead increasing as the load increases.

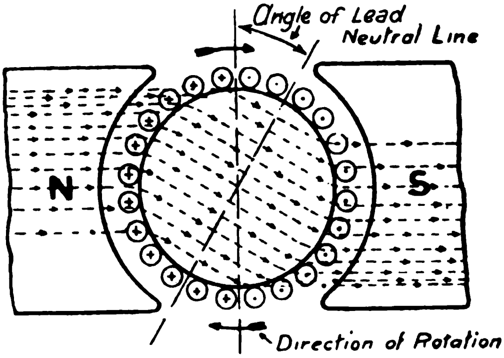


Fig. 78.

Another result is that the magnetic field becomes weakened with increase of load.

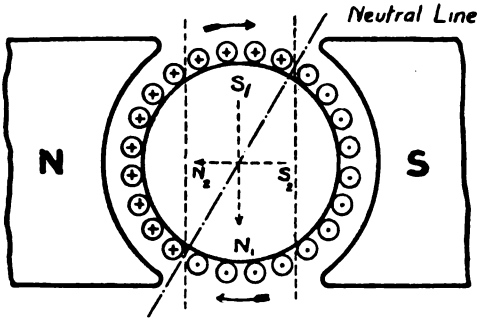


Fig. 79.

Let the conductors be divided into two belts (Fig. 79), forming, as it were, a horizontal and a vertical solenoid around the core, and consider the magnetic field that would be produced by each separately.

The vertical belt produces the horizontal flux $N_2S_2$ acting in opposition to the main flux, and this has a weakening effect on the field. The horizontal belt produces the vertical flux $N_1S_1$ which causes the backward drag the engine has to overcome.

**164. Sparking.**—This is a matter of vital importance. To explain it the form of winding shown in Fig. 80 is adopted.

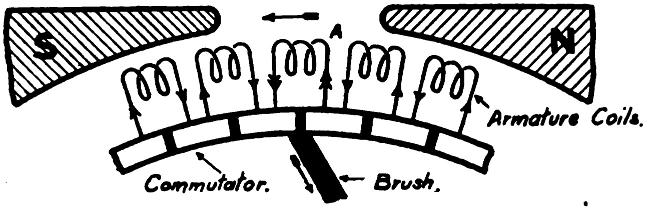


FIG. 80.

The direction of induced E.M.F. and current in the coils under N and S poles are shown, in opposite directions in each set.

Coil A has moved from the right and is at present short-circuited by the brush; the current it carried a moment ago has now to die away, and as soon as it leaves the brush it will have a reverse current forced through it. While its current is falling to zero, an E.M.F. of self-induction is acting in it (shown by double arrow) tending to maintain the current in the original direction.

If this current has not fallen to zero and the induced E.M.F. is still in existence when the segment has just left the tip of the brush, the induced E.M.F. will cause a current to flow through the coil, over the insulation in the form of a spark to the tip of the brush, across the brush and back to the coil.

This is indicated by the dotted line in Fig. 81.

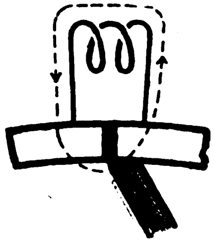


FIG. 81.

Thus the edges of the commutator segments are worn, further increasing the trouble, and the E.M.F. generated is slightly interfered with.

The remedies are:—

(1) The brushes may be of carbon, thus putting a high resistance in the path of the current.

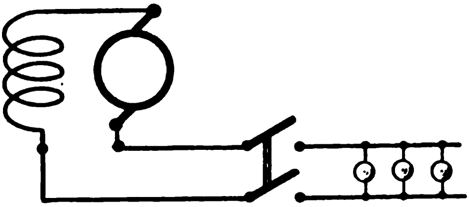
(2) The brushes may be moved slightly ahead of the actual neutral line, thus short-circuiting the coil at a later

stage whilst under the influence of the next pole ahead; then a reverse E.M.F. is induced to assist in stamping out the current and E.M.F. of self-induction of the coil.

(3) The use of interpoles (treated in para. **170**).

In addition, sparking is caused by a dirty and uneven commutator.

**165. Types of Machines: Series Dynamo.** (Fig. 82).—The armature, field magnet winding, and external circuit are all connected in series. The field magnet winding consists of a few turns of cable or copper strip sufficiently thick to carry the total current without undue heating.

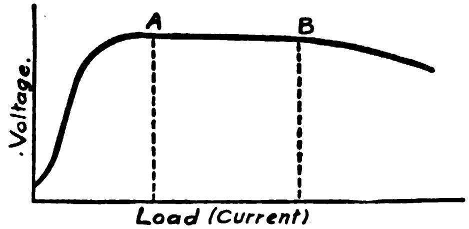


*Series-wound Dynamo.*

Fig. 82.

As the load increases—by a smaller external resistance such as more lamps in parallel—the flux increases, causing increased E.M.F. to be generated.

The Load—Voltage Characteristic Curve (Fig. 83) is similar to the permeability curve of the iron. For loads between A and B (past the saturation point of the iron) the voltage will be fairly steady, but otherwise fluctuating greatly. For this reason this machine is unsuited for the Service.

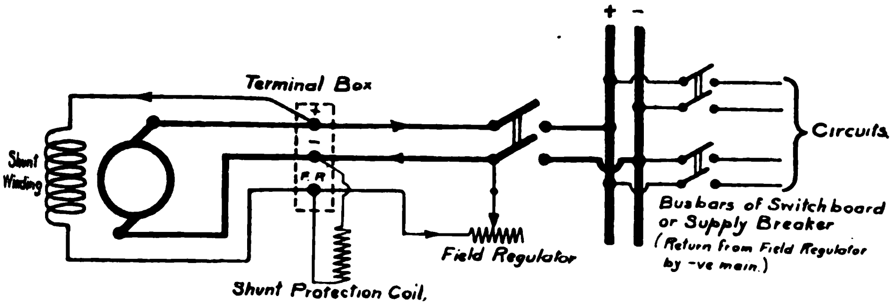


*Load-Voltage Characteristic—Series Machine.*

Fig. 83.

**166. Shunt Dynamo** (Fig. 84).—The field magnet or shunt winding is connected across the terminals and has the full pressure of the mains applied. It consists of many turns of comparatively fine wire and has a high resistance, so that only a small current is taken. The necessary excitation is given by the small current and the large number of turns.

A field regulator, situated at the switchboard, is joined in series with this winding to vary the field magnet current and flux and so regulate the voltage.

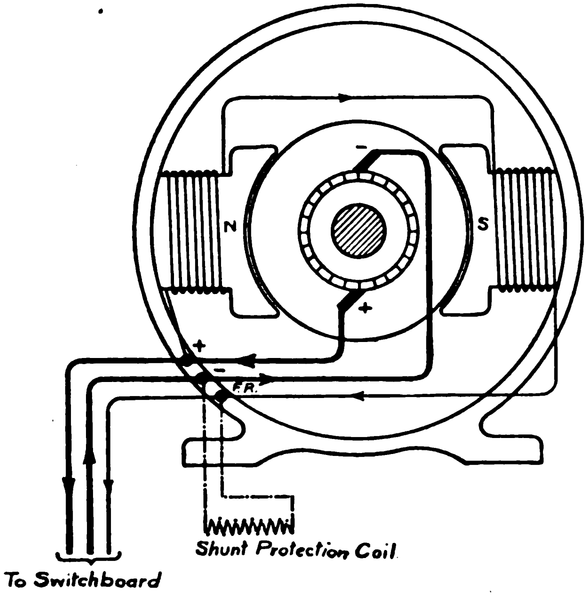

+
-
Terminal Box
Circuits
Shunt Winding
F.R.
Field Regulator
Busbars of Switchboard or Supply Breaker
(Return from Field Regulator by -ve main.)
Shunt Protection Coil,

*Shunt Dynamo.*

Fig. 84.

In parallel with the field regulator (Fig. 84) is a shunt protection coil (eureka wire on a porcelain former) on the dynamo. Its object is to prevent the circuit of the highly inductive field magnet winding being broken, as might happen in the leads to the field regulator or in the latter itself, thus obviating the voltage failing altogether and sparking or arcing at the break, with risk of fire and possibly danger to life.

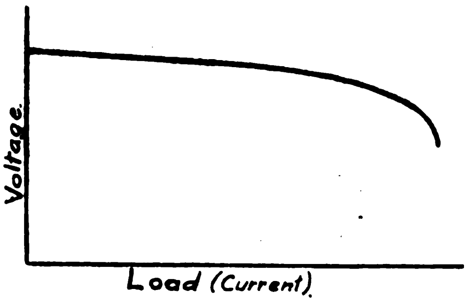
Fig. 85 illustrates a shunt dynamo, showing windings and connections.



*Shunt Dynamo.*

Fig. 85.

**Load-Voltage Characteristic Curve.**—As the load increases the voltage falls gradually as Fig. 86.



*Load-Voltage Curve, Shunt Machine.*

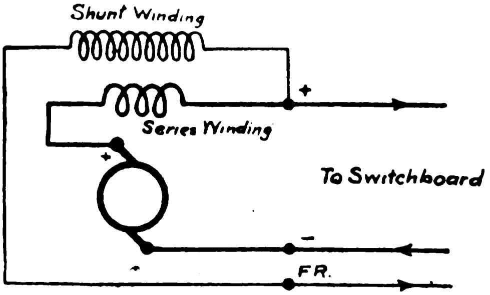
FIG. 86.

This is due to the increased IR drop in the armature giving a smaller terminal P.D., which in turn gives a reduced field magnet current and flux, thus reducing the E.M.F. generatel and still further reducing the terminal P.D.

**167. Constant Speed.**—It may be mentioned here that the speed of the engine is kept constant by the action of a " governor " on the engine, which operates with change of speed and controls the pressure of steam admitted to the cylinders by the valve.

As the load on the dynamo is increased and the engine tends to slow down, a greater pressure of steam is admitted to the cylinders to cope with the increased load, and the original speed is recovered.

**168. Compound Dynamo.**—This type may be looked upon as a shunt dynamo with a suitable number of series turns on the pole-pieces, in addition to the shunt winding, to pick up the falling voltage due to the shunt winding on increased load, and so to give a practically steady voltage at all loads (Fig. 87).



*Compound Dynamo.*

FIG. 87.

**169. Modern Machines** are usually shunt wound, with modifications, this type having been improved so as to fulfil the desired conditions of steady voltage, and are preferable in many respects to the compound type previously in general use. The improvements have been effected by reducing armature resistance (fewer armature conductors in series or more parallel paths through the armature, both necessitating higher speeds), and by interpoles with compounding effect.

**170. Interpoles** are small auxiliary poles placed midway between the main poles, wound in series with the armature and have the same polarity as the main poles next ahead of them in the direction of rotation (Figs. 88 and 89). They are introduced for the following reasons:—

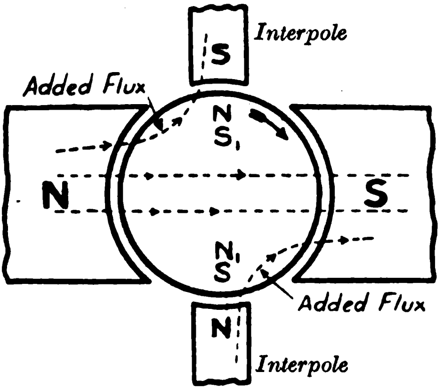
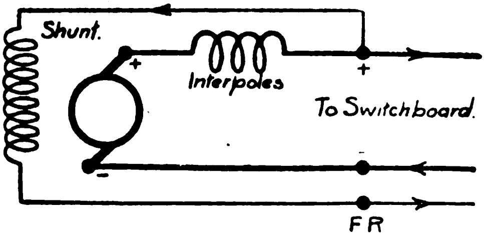


FIG. 88.

(1) To neutralise armature reaction. The interpole flux opposes that of the armature current; interpoles S, N, induce polarity N, S, in the armature neutralising respectively $S_1$ $N_1$ that the armature current tends to set up, each pair at all times being proportional in strength to the armature current.



Shunt Dynamo with Interpoles

FIG. 89.

(2) To correct the sparking defect. The armature coils during their short-circuited period under the brushes come under the influence of the interpoles (their polarity being that of the next main poles ahead) and so have induced

in them the requisite amount of E.M.F. in the reverse direction to stamp out the current and E.M.F. of self-induction before the coils leave the brushes. This is equivalent to the method already explained of giving the brushes extra lead to overcome sparking.

(3) To produce a "compounding" effect sometimes, their flux being added to the main flux (Fig. 88) and for this purpose they must be wider and more powerful than when simply arranged for (1) and (2).

**171. Formula for Voltage of a Dynamo.**—It was stated in para. **104** that the E.M.F. induced in a conductor which cuts through $\Phi$ lines of force in a second is equal to $\frac{\Phi}{10^8}$ volts.

Let the symbol $\Phi_p$ denote the **flux per pole** of the two-pole machine illustrated in Fig. 77.

In one revolution the flux cut by one inductor $= 2\Phi_p$.

If the machine is revolving at n revolutions per second, the flux cut by one inductor will be

$$2\Phi_p \times n \text{ lines per second.}$$

Therefore the voltage induced in one inductor

$$= \frac{2\Phi_p \times n}{10^8} \text{ volts.}$$

From a consideration of the construction of an armature, and of the action of a commutator as described in preceding articles, it is clear that all the inductors in each half of the armature winding are acting in series, and that the two halves of the armature winding are acting in parallel.

Now, if a number of cells, all of the same voltage are arranged in a number of equal groups in parrallel, the cells in each group being in series, the total voltage is

(the number of cells in each group) × (the voltage of each cell)

The conductors in an armature correspond to cells so arranged.

If therefore there are N inductors in the armature winding, each half contains $\frac{N}{2}$, and therefore the voltage generated between the brushes will be

$$\frac{2\Phi_p \times n}{10^8} \times \frac{N}{2} = \frac{\Phi_p \times N \times n}{10^8} \text{ volts.}$$

To calculate the E.M.F. induced in any D.C. generator armature, the following formula may be used

$$V = \frac{P \times \Phi_r \times N \times n}{10^8 \times a} \text{ volts}$$

where P = No. of poles and a = No. of parallel conducting paths between the positive and negative brushes.

**172. The current** will depend on the dynamo E.M.F. and on the total resistance of the circuit, comprising the resistance of the outside circuit joined between the brushes and that of the two halves of the armature winding in parallel.

**173. Commutator and Brushes.**—The commutator consists of strips of copper, insulated—usually by mica—from one another and from the shaft, about which it is built in the form of a cylinder.

The brushes are usually of graphitic carbon, which has a high resistance and keeps down sparking, keeps the commutator clean, is soft and does not wear out or groove the commutator, but takes the shape of the commutator.

They are copper plated at the point where they make contact with their holders.

They are held in brush-holders and the latter in a "brush rocker," enabling the brushes to be shifted all together round the commutator and fixed in position.

**174. Losses.**—The losses suffered are :—

(1) Copper losses in the armature and field windings.

(2) Eddy current loss.

(3) Hysteresis loss—another iron loss—is the disinclination of the iron to become magnetised and demagnetised immediately the magnetising and demagnetising forces are applied; it is the "lagging behind" of the magnetisation.

The iron core in the armature of a 2-pole machine has its magnetisation reversed twice every revolution, and to effect this at a certain rate an expenditure of energy is required from the engine.

(4) Friction and windage. Here, again, force is required to overcome the friction of the bearing and brushes and also the air resistance as the armature revolves, and this force in proportion to the speed represents an expenditure of energy.

**175. Rating of Dynamos.**—The rating of a dynamo is the kilowatt-power-load that the machine will carry continuously without excessive (1) heating, (2) sparking, or (3) internal voltage drop.

Thus, if a maker puts a label on a machine he sells :—

500 amps.
100 volts.
2,400 revs.

he guarantees—

(*a*) that if the machine is kept revolving at 2,400 R.P.M. it will always generate a brush P.D. of 100 volts:

(*b*) that it will stand a maximum current output of 500 amps. without developing any of the faults referred to above.

The electrical output can be found in kilowatts by dividing the product of volts and amps. by 1,000, *i.e.*—

$$\text{Kilowatts} = \frac{E \times I}{1000}$$

The output in horse-power (H.P.) is found by dividing the power in kilowatts by ·746, *i.e.*—

$$\text{H.P.} = \frac{\text{kW}}{\cdot 746}.$$

The **efficiency** of a dynamo is the ratio of the electrical power delivered from it to the mechanical power received by it, or—

$$\text{Efficiency per cent.} = \frac{\text{Output} - \text{Losses}}{\text{Input}} \text{ or}$$

$$\left(\frac{\text{Output}}{\text{Output} + \text{Losses}}\right) \times 100.$$

If the horse-power required to drive it is indicated by H.P., and the electrical power it delivers is indicated by kW., then

$$\text{its efficiency per cent.} = \frac{\text{kW.} \times 100}{\cdot 746 \times \text{H.P.}}$$

**Example 21.**

**What horse-power is required to drive a 150 kW. dynamo when it is developing its full-rated load, if the machine has a full-load efficiency of 91·5 per cent?**

$$\text{H.P.} = \frac{150 \times 100}{\cdot 746 \times 91\cdot 5} 220.$$

## THE MOTOR.

**176. The Electric Motor** is a device for converting electrical energy into mechanical energy. A motor is just the opposite of a generator. It will supply mechanical power when a current due to some external source of E.M.F. is forced through its armature windings.

Its motion is due to the action between the magnetic fields due to the currents passed into its armature and field magnet windings.

**Action.**—Current from the mains is supplied to the field magnet and armature windings.

It has been explained in para. **101** that when a conductor carrying current is placed in a magnetic field, the resultant field—that due to a combination of the original field and the field due to the current in the conductor—is stronger on one side of the conductor than on the other.

In Fig. 90 is shown an armature, with a few only of the armature bars indicated; they are carrying currents, with resultant fields, in the directions shown.

It is clear that the cross magnetic field will combine with the armature fields in the manner indicated, and that forces will be developed on the armature bars which will force those on the left to move up, and those on the right to move down.

**177. Torque** is the twisting effect exerted between the field magnet poles and the armature. On the torque depends the raising of the load. Torque is measured in ft.-lbs., and is calculated by multiplying the total pull on all the armature conductors (P lb.) by the radius of the armature (r ft.), *i.e.*, Pr.

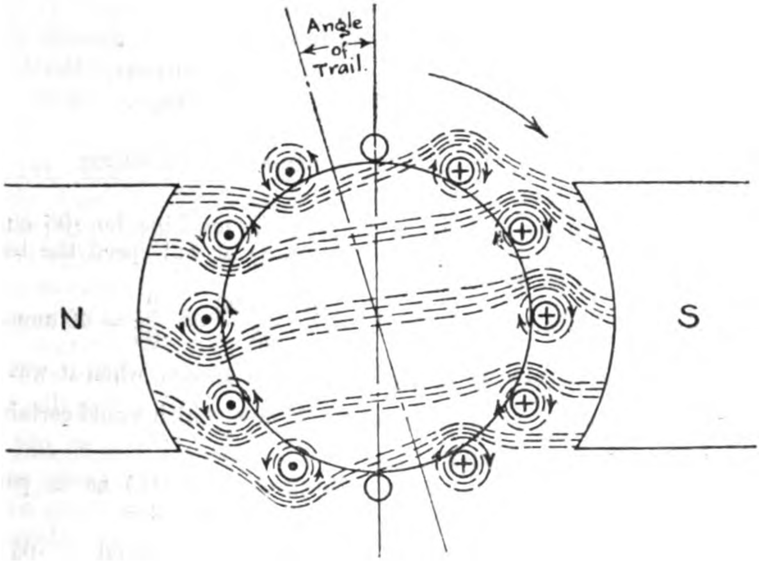
ft.-lbs. For our present purpose it will not be necessary to deal with it in this form, but as follows:—

As both NS and $N_1S_1$ (Fig. 88) vary in strength, the torque will vary directly with them :—

$$\text{Torque} \propto NS \times N_1S_1$$

$$\text{i.e., } \propto I_F \times I_A \text{ (field magnet and armature currents).}$$

(The last statement is not strictly correct, but in the absence of the permeability curves for the specimens of iron in use, it will be assumed that the flux is proportional to the current.)



*Illustrating Action of a Motor.*

FIG. 90.

The torque is practically constant for a given load at steady speeds, and if the load is increased the torque is proportionally increased.

The current taken by the motor is determined by the load and the speed.

**178. Back E.M.F. When the armature conductors cut through the flux, E.M.F.s are induced in them just as in the dynamo.**

These E.M.F.s give a certain total "back E.M.F." corresponding to the total E.M.F. generated in a dynamo.

The back E.M.F. induced in any D.C. motor armature is the E.M.F. which the same armature would develop if operated as a generator at the same speed and in the same flux.

The effect of back E.M.F. is to limit the current in a motor armature.

The resistance of any motor armature is small; usually it is much less than one ohm.

Hence it is evident that if the normal line E.M.F. is impressed directly on a stationary armature, an excessive current would flow unless there is something to limit the current to a reasonably safe value. As is explained in para. **182**, resistance is inserted in series with an armature by means of **the starter,** to limit the current while the motor is gathering speed.

After the armature has commenced rotating, the back E.M.F. of the armature limits the current, and the starter resistance is cut out of circuit.

When the motor is running, the back E.M.F. and the ohmic drop in the armature winding, are together equal to the applied voltage, that is

$$V = e + I_A R_A,$$

and conversely the armature current will be

$$I_A = \frac{V - e}{R_A} \text{ where } \begin{cases} I_A = \text{armature current.} \\ V = \text{applied voltage.} \\ e = \text{back E.M.F.} \\ R_A = \text{armature resistance.} \end{cases}$$

**Example 22.**

Let the armature resistance of a certain machine be ·05 ohm, and the applied voltage 100 volts. Suppose at full speed the back E.M.F. developed = 98 volts.

Then the armature current $= I_A = \frac{100 - 98}{\cdot 05} = \frac{2}{\cdot 05} = 40$ amps.

If the full 100 volts were applied to the armature when it was at rest, a current of $\frac{100}{\cdot 05} = 2{,}000$ amps. would flow, which would certainly burn it out if it did not blow a fuse.

Consequently we must use a starting resistance ($R_s$) as in para. **182**, to limit this current to (say) 60 amps., as follows :—

$I_A = \frac{V}{R_A + R_s}$ or $R_s = \frac{V}{I_A} - R = \frac{100}{60} - \cdot 05 = 1\cdot 66 \quad \cdot 05 =$ 1·61 ohms.

Hence we shall need a resistance in the starter of 1·61 ohms which we shall cut out gradually as the machine gathers speed and starts generating a back E.M.F.

A current is needed at starting rather larger than when the machine has reached its normal speed, on account of the inertia of the armature which needs to be overcome.

**179. The power** taken from the mains $= V \times I$. Of this a power of $I_A^2 \times R_A$ will be expended in heating losses in the armature.

The power developed by the motor, including that available at the motor shaft for driving the load and expended in friction, windage, eddy current and hysteresis losses $= e \times I_A$.

**Example 22 continued.**

In the above example, the power taken from the mains will be 100 × 40 = 4,000 watts.

Of this $40^2 \times \cdot 05 = 80$ watts is expended in heating the armature.

The remainder, 98 × 40 = 3,920 watts, represents the total power developed by the motor, neglecting the heating losses in the field magnet windings.

**180. Types of Motors: Series Motor.**—The armature and field magnet windings are in series; the latter is a heavy winding of a few turns as in the dynamo of this type.

It gives a powerful starting torque, as the large initial current passes through both the field magnet and armature windings, consequently it will speed up quickly and a starter is not always necessary. This applies more particularly to small series motors, in which, in addition to the above, the higher inductance of the field magnet winding and armature (which has a large number of turns) will prevent the initial current rising too rapidly. Also the resistance of small motors (series and shunt) is usually high enough to prevent excessive currents flowing.

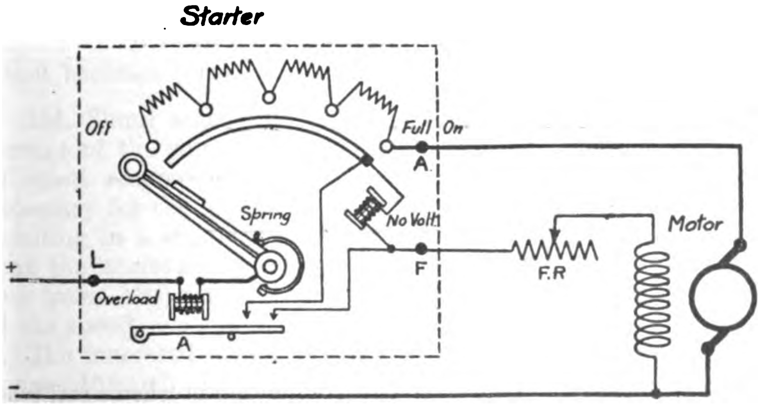
Another important feature is that as the load is increased the speed is appreciably decreased. The reason will be given later.

**181. Shunt Motor.**—The field magnet or shunt winding, of many turns and of high resistance, is connected across the mains, thus having their full pressure. (Fig. 92).

It chief characteristic is that its speed falls off only slightly with increase of load; it is the type adopted for driving shafting in a workshop, amd for the motor buzzer, motor generator, and motor alternator.

The compound motor is not in common use in the Service and will not be dealt with here.

**182. Motor Starter.**—The main object of the motor starter is to insert resistance in series with the armature on starting, to be gradually removed as the speed and back E.M.F. rise. It generally embodies, in addition, safety devices—the overload and no-volt coils. Fig. 91 shows a typical form connected to a shunt motor.



*Motor Starter.*

Fig. 91.

(N.B.—In sketching any form of motor starter always commence with starting resistance, armature and overload coil in series; then the no-volt coil in series with shunt winding.)

The starting resistance is usually capable of carrying the armature current for a short time only without overheating, and consequently the starter arm should not be held on an intermediate stop for any length of time.

**No-volt Coil.**—When the starter-arm reaches the "full on" position, it is held there by the no-volt coil, which is energised by the shunt current (or in a series motor starter by a high resistance winding across the mains). Should the supply to the motor fail, this coil will cease to be energised, and the arm will be returned to the "off" position by a spring, so that when the supply is again available the motor must be started in the usual manner.

**Overload Coil.**—The overload coil is always energised when the motor is running, but not strongly enough under normal conditions to attract the "armature" A. The latter is set at a certain distance which can be regulated, and has to be attracted against the force of gravity, or of a spring, when the overload occurs. It then makes contact with two studs (in above type) and the no-volt coil is short-circuited, the arm returns to the "off" position, and the motor is thus disconnected from the mains.

**183. Speed Regulation.**—The speed of a shunt motor may be increased by inserting resistance in series with its field.

Since the back E.M.F. corresponds to the generated E.M.F. of a dynamo, we can say that

$$\text{back } e \propto \Phi \, Nn, \text{ and } N \text{ being constant}$$

$$n \propto \frac{e}{I_F} \text{ (assuming flux proportional to field-magnet current).}$$

That is, the speed is directly proportional to the back E.M.F. and inversely proportional to the field-magnet flux.

The following example illustrates speed variation :

**Example 23.**

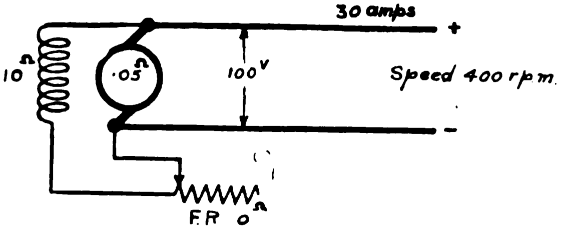


Fig. 92.

It is required to find the speed of this shunt motor when a resistance of 2·5 Ω is inserted in the field regulator, the load remaining unaltered.

$$I_F = \frac{100}{10} = 10 \text{ amps.} \quad I_A = 30 - 10 = 20 \text{ amps.}$$

$$\text{IR drop in armature} = 20 \times \cdot 05 = 1 \text{ volt.}$$

$$e = 100 - 1 = 99 \text{ volts.}$$

The torque necessary to deal with the load is proportional to $I_A \times I_F$, and

$$I_A \times I_F = 20 \times 10 = 200.$$

Insert $2\cdot5$ ohms in series with the field.

Now as the load remains constant, the torque will remain constant when the speed again becomes steady.

$$\text{New } I'_F = \frac{100}{12\cdot5} = 8 \text{ amps.}$$

$$\text{Hence new } I'_A = \frac{I_A \times I_F}{I'_F} = \frac{200}{8} = 25 \text{ amps.}$$

(Thus $I'_A \times I'_F = 8 \times 25 = 200$ as before.)

IR drop in armature $= 25 \times \cdot05 = 1\cdot25$, and $e = 98\cdot75$ volts.

$$\text{New speed} = 400 \times \underset{(a)}{\frac{98\cdot75}{99}} \times \underset{(b)}{\frac{10}{8}} = 500 \text{ r.p.m. nearly.}$$

(*a*) Decreased back E.M.F. represents a smaller speed, but

(*b*) $I_F$ is reduced from 10 amps. to 8 amps., hence speed will be increased in the proportion of 8 to 10.

Note how the torque is introduced to determine the new current—a greater current being required to run the same load at a greater speed.

The increase in speed is almost entirely due to the change of flux, the change in back E.M.F. due to the small armature IR drop being negligible.

The self-regulating action in the above case is briefly thus: the F.M. current is reduced; to compensate for this so as to give the necessary torque more current must enter armature; back E.M.F. falls and allows more current to enter than is necessary for the required torque; thus an acceleration or speeding up takes place until the back E.M.F. regulates the current to the correct value for the load or torque, when the speed becomes steady.

**184. Shunt and Series Motors on Increased Load.**—The F.M. current of the **shunt motor** remains constant; hence no change in speed occurs due to this factor; more armature current is necessary for the greater load and the back E.M.F. falls slightly, resulting in a slightly decreased speed. It may also be noticed that the armature reaction produces a slight weakening of the flux (para. **186**) which may account for a total or partial recovery of the speed.

The increased current required by the **series motor** flows, of course, through the F.M. coils, the flux is strengthened, and in consequence the motor slows down, also the back E.M.F. is slightly reduced resulting also in a reduction in speed.

**185. Methods of producing Speed Variation.**—(1) **Shunt Motor.**—For slower speeds, insert resistance in series with the armature (reduction in speed due solely to fall of back E.M.F.).

For higher speeds, put resistance in field regulator.

(2) **Series Motor.**—For lower speeds put resistance in series with motor.

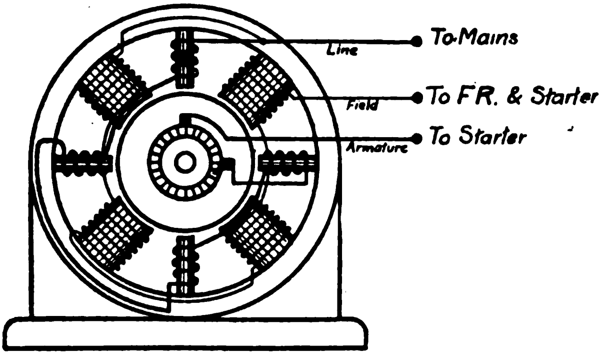
For higher speeds, arrange—by a "Controller"—field magnet coils in parallel (4 pole, 2 in series, 2 in parallel; then 4 in parallel); then in addition a resistance—termed a "Diverter"—across the field magnet coils in parallel. The object is to make the flux weaker as higher speeds are required.

**186. Armature Reaction.**—The effect of armature reaction in the motor is to cause distortion of the flux in the opposite direction to that in the dynamo, *i.e.*, the flux at the leading pole tips is strengthened, and the neutral line receives an angle of lag; thus the brushes must be given "**trail**" or "lag" to bring them on the actual neutral line, and, in addition, a little further trail to effect sparkless commutation.

Also, as in the dynamo, the cross-magnetising effect of the armature current weakens the main flux slightly.

**187. Interpoles** in a motor are wound in series with the armature as in the dynamo, but are of the same polarity as the main poles next **behind** them. Their action is similar to that in the dynamo and they enable the motor to be run sparklessly with fixed brushes at all loads.

Fig. 93 shows the windings and connections for a shunt motor with interpoles.

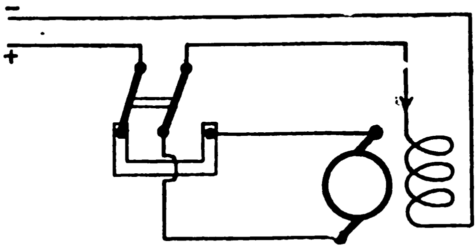


*Shunt Motor with Interpole Windings.*

Fig. 93.

**188. Reversing.**—The direction of rotation of a motor is reversed by reversing the current in either the field magnet winding or in the armature. (Changing over the connections from the mains to the terminals gives the same direction of rotation.) To reverse the motor at will a reversing drum or switch is used as in Fig. 94 (series motor only).

**The current in this case is reversed in the armature only.**



*Reversing Switch for Small Series Motor.*

FIG. 94.

## Motor-Generator, Motor-Alternator and Motor-Booster.

**189. The Motor-Generator** consists of a dynamo driven by a motor, and its function is to generate a voltage differing from that of the supply mains.

The two machines (motor and dynamo) may—

(i) be entirely separate and have their shafts coupled together; or

(ii) be built in one casting, but have separate pole-pieces, armatures and commutators; or

(iii) in smaller types, be arranged in one casting with one set of pole-pieces and one armature, the latter having two distinct windings each with its own commutator at either end (" Dynamotor ").

The step-up or step-down in voltage, on the voltage of the ship's mains, is arranged for by—

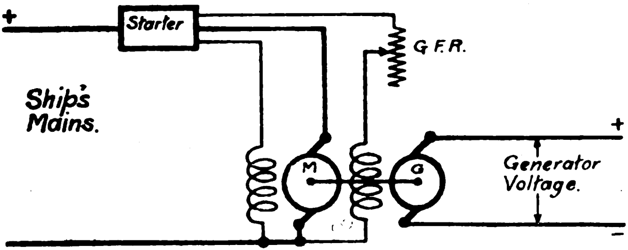
(*a*) the relative number of armature bars in each armature; or,

(*b*) the relative strength of magnetic fields; or,

(*c*) both.

The motor being shunt wound—as is usually the case—runs at a practically constant speed, thus the generator voltage is not dependent on this factor.

Fig. 95 shows a general arrangement of electrical connections.

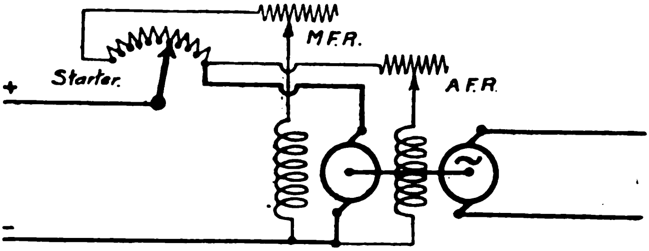


*Motor Generator.*

FIG. 95.

Applications of motor generators in the Service are, among others:—to supply the low power switchboard (20 volts) for bells, telephones, fire-control, &c.; for transmitting valves and Poulsen arc (step-up in voltage); for supplying constant current to searchlights at reduced voltage: for charging secondary batteries, &c.

**190. The Motor Alternator.**—The motor alternator consists of a motor and alternator on one shaft, as illustrated diagrammatically in Fig. 96.



*Motor Alternator.*

Fig. 96.

The motor is fitted with a starter and a field regulator: a separate regulator is supplied for the alternator field current.

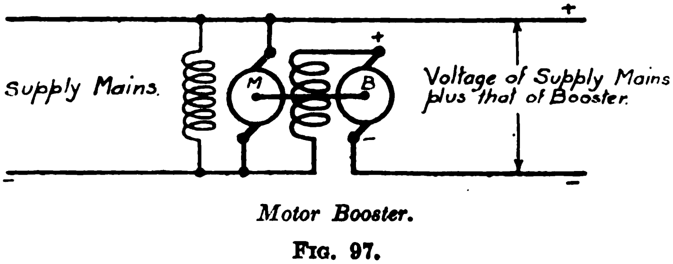
**The Motor Field Regulator** controls the speed of the motor, hence the speed of the alternator, and hence the alternating frequency, and also the voltage to a certain extent.

**The Alternator Field Regulator** controls the density of the alternator field, and hence the alternating voltage independently of frequency.

**191. The Motor Booster** consists of a generator, (run by a motor) in series with the ship's mains, to add its voltage to that of the mains; it is sometimes made to oppose its voltage to that of the ship's mains, for charging secondary batteries.

The generator is frequently a low voltage one of high current capacity. A common use is to pick up the voltage lost due to IR drop in cables in transmitting power to a long distance.

For this purpose the arrangement shown in Fig. 97 would be suitable.

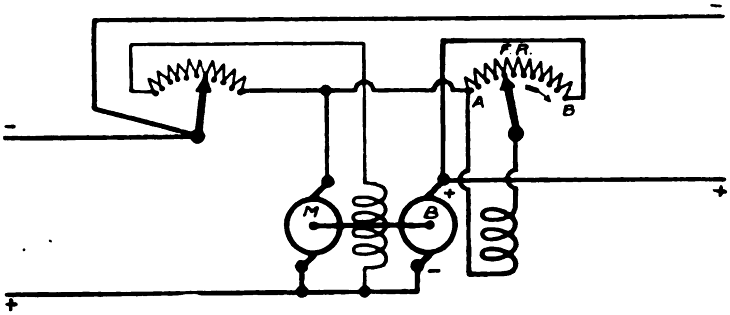


*Motor Booster.*

Fig. 97.

Note that the + ve of booster is connected to the − ve main, so that its voltage is added—just as an additional cell is added to a battery. The booster is series wound, and the greater the current flowing (representing a greater IR drop in the cables) the greater will be the field magnet excitation, and the greater the voltage generated by the booster, thus compensating for the additional IR drop in the cables.

**192**. Another type used in certain W/T sets arranges for voltage regulation by means of a booster field regulator on the potentiometer principle, thus (Fig. 98):—



*Booster—differential Field Excitation.*

Fig. 98.

With the field regulator arm at A the field magnet (shunt) winding is short-circuited, and no current flows through it, but due to the residual magnetism of the booster field a small voltage is obtained from the booster and added to that of the mains.

As the arm moves towards B it becomes more and more positive with respect to A; thus more and more current flows through the F.M. winding, giving greater excitation and voltage. Finally when B is reached the F.M. winding has the combined voltage of mains and booster across it, *i.e.*, this is the position for maximum booster volts.

Note.—In the motor-generator, the generator independently supplies the required voltage; but in the motor booster the voltage generated by the booster is added to that of the mains.

A motor booster is thus a less expensive machine to manufacture than a motor generator for giving the same maximum voltage, because the generator armature has to stand the full generated voltage, while the booster armature has only to stand the difference between the voltage of the ship's mains and the boosted voltage.

**193. The Rotary Converter.**—A rotary converter is a machine with one set of field magnets, usually shunt wound, and excited with direct current.

It has only one armature with a uniformly distributed winding (as in D.C. machines) which has connections to a commutator at one end and, if single phase, tappings to two slip rings at the other. In a two-pole machine these tappings are taken at points 180° apart, in a four-pole machine 90° apart, in an eight-pole machine 45° apart, &c.

Its uses are—

(*a*) Supplied with D.C. at the commutator end, it runs as a D.C. motor, and A.C. is tapped off from the slip rings. This is the Service application.

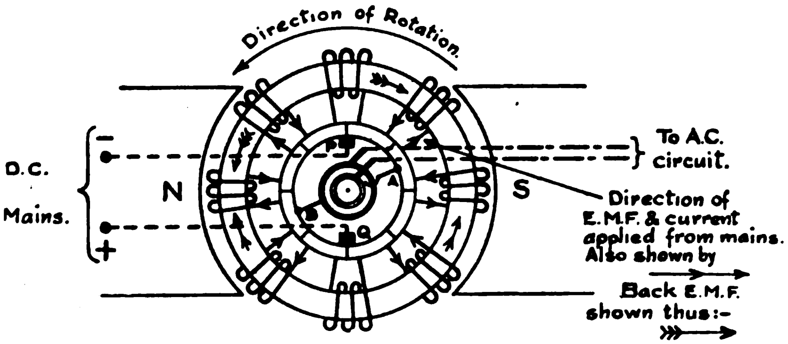
(*b*) Supplied with A.C. at the slip rings, it runs as a motor, and D.C. is obtained from the commutator end. This is the common application in commercial work.

(*c*) If the armature is revolved by an engine, both A.C. and D.C. may be obtained simultaneously. It is then called a "Double Current Generator."

**194. Action**—running as a D.C. motor and delivering A.C. (the Service application).

It is necessary to understand clearly how the back E.M.F. of a motor varies, so we will recapitulate the statements given in para. **178**.

The "Gramme ring" type of armature is illustrated (Fig. 99) for simplicity, its winding being easier to represent than that of a drum armature.



*Diagrammatic Representation of a Rotary Converter.*

FIG. 99.

When a motor is running, the armature conductors have E.M.F.s induced in them (the dynamo action) which by Lenz's Law oppose the E.M.F. applied by the mains.

The sum of the instantaneous E.M.F.'s induced in all the inductors under either pole is called the "back E.M.F.": this is of constant value for a given field magnet flux, speed, and load.

The sets of inductors under each pole, at any instant, are in parallel with respect to the D.C. brushes bearing on the commutator (this should be traced out in Fig. 99).

The back E.M.F. (*e*) will be a little less than the applied voltage (V)—say, 98 volts with 100 volt mains; *i.e.*, 98 volts of those applied balance the back E.M.F., and the other two volts supply the ohmic drop in the armature resistance.

Thus the applied voltage $V = e + I_a R_a$.

**195.** The variations of P.D. between the tapping points A and B (which is the voltage applied to the A.C. circuit) as the armature revolves may now be considered.

Fig. 100 is a further simplification of Fig. 99 drawn to assist in the following explanation. Only four armature bars are shown, namely, the pair lettered A and B which are connected through the slip rings to the A.C. circuit, and the pair lettered P and Q which are in connection with the D.C. brushes at any instant.

For the purpose of this elementary treatment of the rotary converter, the IR drop in the armature will be neglected; in most cases it will be very small owing to the low armature resistance.

Thus we will assume that $e = V$.

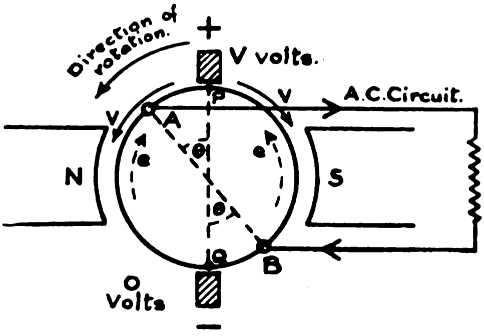


FIG. 100.

When A and B are on the neutral line they will obviously have the P.D. of the mains, (V) or (e), and maximum current will flow in the A.C. circuit.

When A and B have moved through an angle $\theta$ from the neutral line, the potential of A with respect to Q will be

$$V - (\text{back E.M.F. in AP} + \text{IR drop in AP}).$$

Ignoring the IR drop this becomes

$$V - e_{AP} = e - e_{AP}.$$

Similarly the potential of B with respect to Q will be

back E.M.F. in BQ

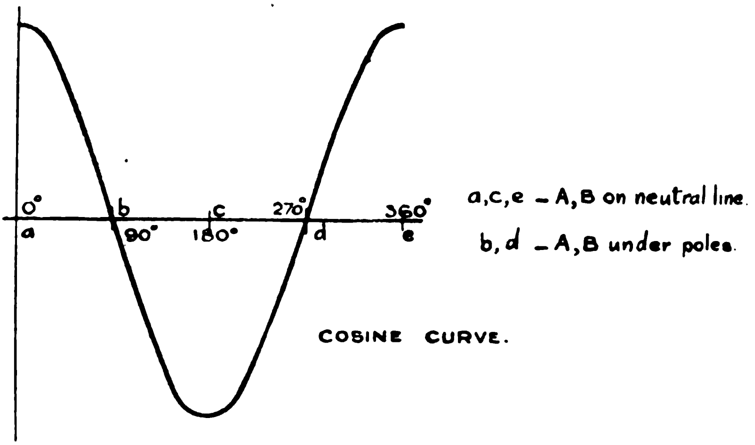
$= e_{BQ}$, which is equal to $e_{AP}$.

Thus the P.D. between A and B $= (e - e_{AP}) - e_{BQ}$

$= e - 2e_{AP}$.

This can be shown mathematically to be equal to $e \cos \theta$.

Fig. 101 shows e cos $\theta$ plotted and represents the variations in the P.D between A and B for one revolution. This curve is a cosine curve, which is merely a sine curve moved 90° to the left so that P.D. follows a sine law, tracing out one cycle in each revolution.



*Voltage between Slip Rings.*

FIG. 101.

The following points should be specially noted:—

(1) When A and B are under the D.C. brushes, $\theta = 0$; therefore $e_{AP} = 0$, and the P.D. $= e = V$.

(2) When A and B are centrally under the poles ($\theta = 90°$) $e_{AP}$ will be equal to $\frac{1}{2}e$, so that $e - 2e_{AP} = e \cos 90° = 0$.

(3) A, when between 0° and 90°, has a higher potential than B.

(4) When $\theta = 180°$ and A is under the negative brush, the P.D. $= -e = -V$, and so on for the next half revolution.

**196.** As regards the currents: in the position of A and B shown in Fig. 100, the **motor current** will follow the course . . . + ve brush, PAQ and PBQ in parallel, to the — ve brush: the **alternating current** will follow the course . . . + ve brush, PA, external circuit, BQ, to — ve brush.

Both the motor and the alternating currents are supplied by the mains.

Thus, the portions of the winding AP and BQ will carry at this stage, more current than the other portions, thus causing additional and varying field distortion and armature reaction.

When A has passed beyond the centre of the left pole piece, it will be negative to B, and the course of the alternating current will be—

+ve brush, PB, external circuit, AQ, to —ve brush.

**197. Armature Reaction.**—The armature reaction of a rotary converter, as in dynamos and motors, has important effects in practice.

The A.C. circuit may consist of

(1) a pure resistance load;
(2) a combined resistance and capacity load;
(3) a combined resistance and inductive load;
(4) a combined resistance, capacity, and inductive load.

The combined armature reactions are rather complicated to follow, and no attempt will be made here to describe them.

Their effects, in so far as their results affect the practical running of machines is concerned, may be summarised as follows:—

(1) A pure resistance load causes a small resultant cross magnetising field and a slight decrease of speed.

(2) A purely inductive load causes a demagnetising field and consequently an increase of speed.

(3) A pure capacity load causes a magnetising field and consequently a decrease of speed.

Combinations of these loads give a resulting speed retardation or acceleration depending on which preponderates.

**198. Frequency, Voltage, and Current.**—The frequency of the alternating current delivered by a rotary converter, as with an alternator, is equal to $\frac{\text{R.P.M.}}{60} \times$ pairs of poles.

The **maximum** value of the **voltage** will be a little less than that of the D.C. mains and can never exceed it.

The "R.M.S. value" (*see* next chapter) will be a little less than ·707 of that of the D.C. supply, *e.g.*, in the case of a 100-volt D.C. supply the R.M.S. alternating voltage which will be given by a rotary converter is a little less than 70·7 volts.

The relations between the alternating and direct **currents** can be found approximately from considerations of power.

If there are no losses in the machine the alternating output would equal the direct current input (in watts).

Assume, for the sake of argument, a perfectly efficient machine running at 15 ampères on 100 volts direct.

The input is 1,500 watts or 1·5 kilowatts.

The alternating volts are 70·7 R.M.S., so that 70·7 × R.M.S. current = output in watts = input = 1,500 watts.

The alternating current has, therefore, an R.M.S. value $\frac{1{,}500}{70 \cdot 7} = 21 \cdot 23$ ampères.

This is greater than the direct current, a result which at first sight appears peculiar. It is accounted for by the fact that current is taken from the mains as well as from the rotary. The excess of output current over input will not be quite so marked as is shown by this example, owing to the efficiency of the machine not being 100 per cent., but it is at any rate a factor which may have to be taken into account.

**199.** With a rotary converter, a normal-type starter and a motor field regulator are provided.

As with a motor, when resistance is inserted in series with the field, the machine speeds up; thus the **frequency** of the alternating voltage will be increased.

The value of the voltage remains approximately the same, since it depends on the applied voltage, and is approximately 65 per cent. of that of the D.C. supply.

**200. Advantages and Disadvantages of the Rotary Converter.** For W/T purposes, rotary converters are used for moderate power and frequency only.

They are lighter than motor alternators, as a rotary has one armature only, but labour under the disadvantages (*a*) that they can only give an R.M.S. voltage **less** than that of the D.C. supply; (*b*) that it is very difficult to make them for high frequencies.

## THREE-PHASE CURRENT.

**201.** The following brief description of three-phase currents, and of the motors and generators used with them, is inserted because they are sometimes used in the supply of power, to shore stations, and to transmitting valve sets.

Three-phase currents are very widely used in the commercial world in the transmission of power over long distances, on account of the fact that they require conductors of a less total cross-section for the conveyance of equivalent power than single-phase currents.

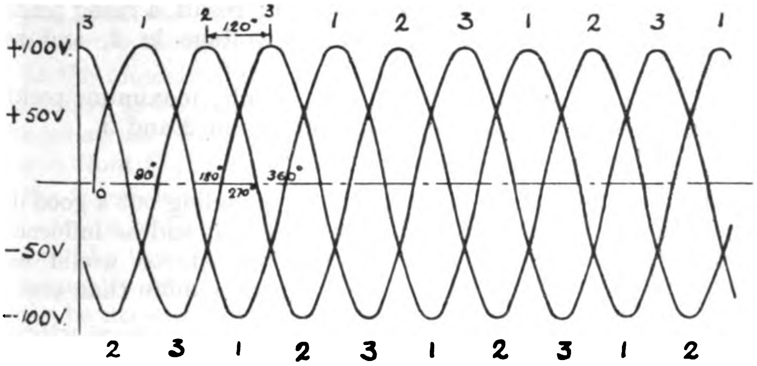
**202.** It will be noticed in the diagrams of alternators in Figs. 61 and 62 that there are portions of the armature which do not carry any winding.

In a three-phase alternator we fit three separate and distinct windings into the armature, spacing them symmetrically round its circumference, *i.e.*, with similar poles 120° apart.

We thus generate three separate alternating currents. These three currents will not be in step with one another, but will rise to their maxima values in succession, as shown in Fig. 102.

They are said to differ in phase by 120°.

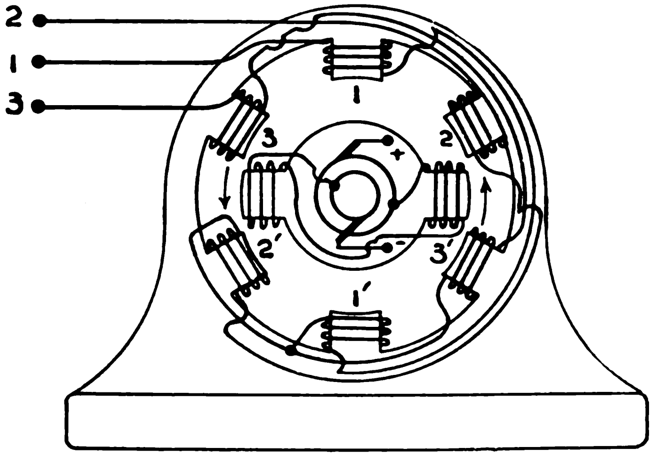
An inspection of this curve will show that when No. 1 is zero, Nos. 2 and 3 are equal and opposite; when No. 1 is maximum Nos. 2 and 3 are each of half the amplitude of No. 1; in fact, **that at any moment the sum of the three currents is zero.** In consequence, as will be explained later, only three wires are required to carry them instead of six, as might have been expected.



*Three Phase Currents.*

FIG. 102.

**203. Three-phase Generators** are usually of the revolving field type (para. 157). Fig. 103 gives a diagrammatic picture of a typical machine.



*Three-Phase Generator, or Synchronous Motor.*

FIG. 103.

It will be noticed that the poles of the armature are wound alternately right and left handed, and that similarly wound poles are 120° apart.

The direction of the voltage induced as the field sweeps round will depend on the direction in which each pole is wound.

Let us take the rotor in successive positions 30° apart, and check the direction of the voltage with Fig. 102.

(1) Rotor poles between stator poles 2 and 3; result, a falling positive voltage in 3, a rising negative voltage in 2, and zero voltage in 1.

(2) Rotor poles opposite 2; result, a maximum negative voltage in 2, equal positive voltages in 3 and 1.

(3) Rotor poles between 2 and 1; result, a rising positive voltage in 1, a falling negative voltage in 2, and zero voltage in 3.

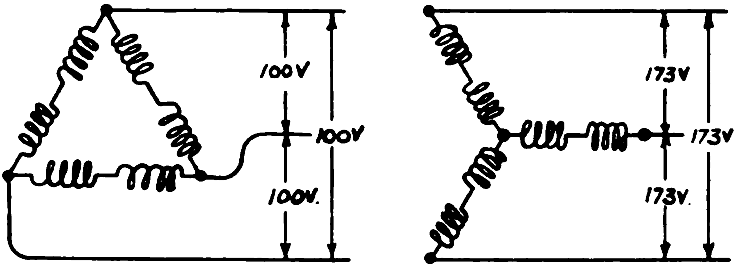
(4) Rotor poles opposite 1; result, maximum positive voltage in 1, equal negative voltages in 2 and 3,

and so on.

The rotor field must be imagined as spreading out a good deal more than would be expected from Fig. 103, and as influencing adjacent poles; actually in practice the stator would have more than three pairs of poles, and the rotor more than one.

**204. Three-phase Connections.**—Both the armature windings of motors and generators, and the loads joined between the wires, may be connected up in one of two ways, viz. :—

(*a*) The Delta or Mesh connection.
(*b*) The star or Y connection.



*Delta Connection.* *Star Connection.*

FIG. 104.

With the **Delta** connection, the maximum voltage between any pair of wires is equal to that generated in one armature winding.

With the **Star** connection, the maximum voltage between any pair of wires is equal to $\sqrt{3}$, or 1·732 times that generated in one armature winding.

**205.** In order to explain why no return wire is needed with the three-phase system, Fig. 105 has been inserted.

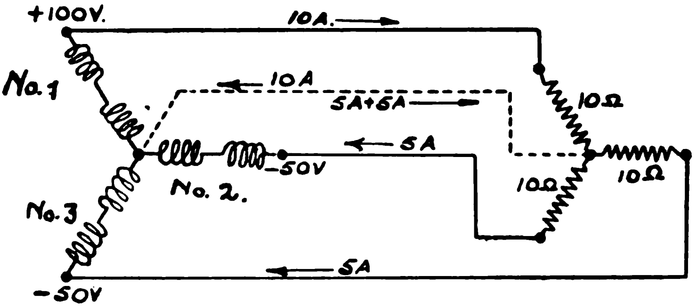


FIG. 105.

The generator windings, and the three-10-ohm resistances joined across them as a load, are both star-connected.

At the moment illustrated, the voltage across No. 1 winding is assumed to be 100 volts positive; at the same moment the voltages across Nos. 2 and 3 windings will be − 50 volts, as can be seen from Fig. 102.

If a fourth wire were joined up as shown dotted, there would be a current of 10 amps. flowing from right to left in it, counterbalanced by the two currents of 5 amps due to windings 2 and 3. Consequently **no** current would flow along the dotted wire, and it may be dispensed with.

This really means that each wire acts as a common return for the other two in turn.

**206. The Rotating Field.**—A special advantage that three-phase currents possess is the fact that they can be made to produce a rotating field.

Just as they are generated by the use of a rotating field, so when they are applied to a motor they produce a rotating field.

Consider the effect of the three-phase currents shown in Fig. 106 as applied to the field of the Induction Motor shown in Fig. 107; remember that a positive current through a right-hand pole will produce the same polarity as a negative current through a left-hand pole.

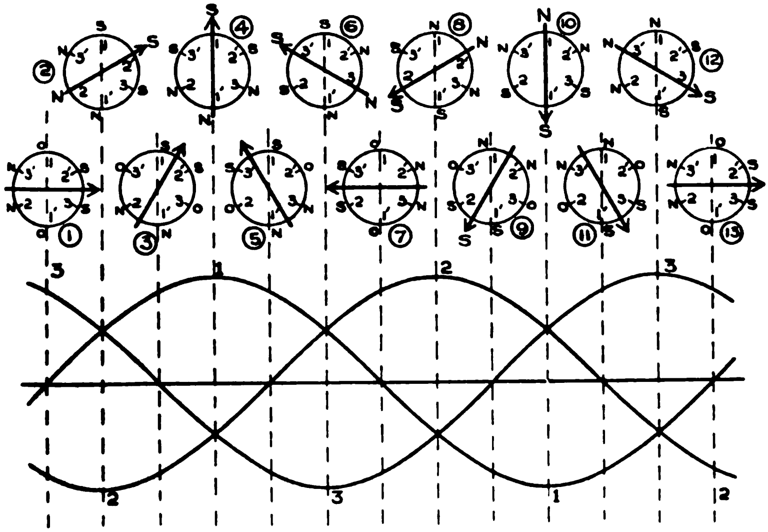


*Diagram of Rotating Field.*

Fig. 106.

Moment 1. Field of poles 1, 1′ zero; fields of poles 2, 2′ and 3, 3′ equal, resultant midway between 2, 2′ and 3, 3′.

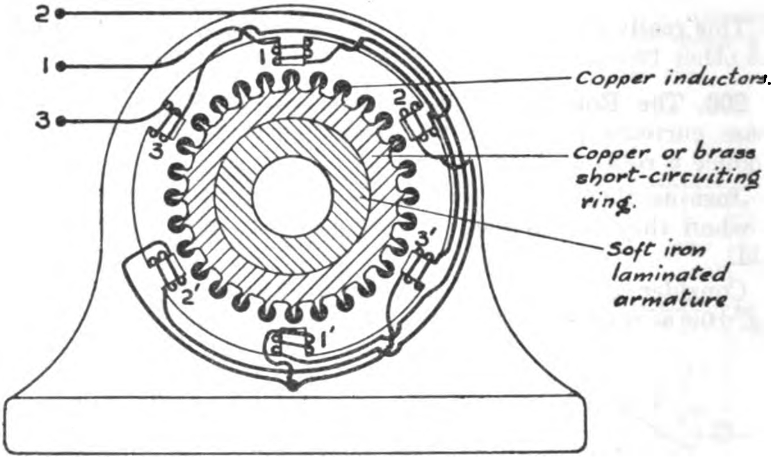
Moment 2. Field of poles 2, 2′ maximum; fields of poles 1, 1′ and 3, 3′ symmetrical on either side; resultant across 2, 2′.

Moment 3. Field of poles 3, 3′ zero; fields of poles 2, 2′ and 1, 1′ equal; resultant midway between 2, 2′ and 1, 1′.

Moment 4. Field of 1, 1′ maximum; fields of poles 2, 2′ and 3, 3′ symmetrical on either side; resultant across 1, 1′; and so on.

Thus the position of maximum field strength will rotate at the same frequency as that of the applied alternating current.

### 207. The Induction Motor; Squirrel-cage Type.


2
1
3
Copper inductors.
Copper or brass short-circuiting ring.
Soft iron laminated armature
1
2
3
3′
2′
1′

*Induction Motor. Squirrel-Cage Type.*
Fig. 107.

A very simple type of motor is that illustrated in Fig. 107. The rotor simply consists of a number of copper inductors joined together at each end.

**Action.**—The effect of the rotating field will be to induce alternating currents in the rotor inductors.

The reaction of the fields produced by these currents with the rotating field of the stator will cause the rotor to move, and it will speed up until it is revolving at nearly the same pace as the stator field.

This is in accordance with Lenz' Law, which, put colloquially, says that all inductive effects are suicidal in tendency.

The rotor would like to run at exactly the same speed as the stator field, but then there would be no currents induced in it. It therefore runs a little bit slower, and what is termed "slip" sets up. "Slip" increases slightly with the load.

### 208. The Induction Motor; Wound Rotor Type.

The squirrel-cage type is very useful for comparatively small loads, but it fails when heavy loads have to be started up from rest.

For starting against heavy loads a " Wound Rotor " type is used. (In England the majority of motors of 10 H.P. and over are furnished with wound rotors.)

In this type the rotor is wound with a three phase winding, connected to three slip rings.

The starter used is a group of three resistances connected in star or delta and joined between the slip rings.

As the machine gathers speed, these resistances are cut out till eventually they are out of circuit, the windings are short-circuited on themselves and the brushes are raised. The machine then behaves in the same manner as the squirrel-cage.

### 209. The Synchronous Motor.

In cases where an absolutely constant speed is required, without slip, a " Synchronous Motor " is used.

This is very similar in design to the generator shown in Fig. 103 and the same diagram may be used.

Its drawback is that it is not self-starting. To start it we must disconnect the three phase supply from its stator, and rotate it mechanically by the use of (say) an induction motor on the same shaft, until its rotor field is revolving at the same frequency as that of the three-phase supply.*

If then the three-phase supply is switched on to the stator, the rotating field of the stator will drive the rotor round without any slip.

If, however, current is switched on at the last moment, a heavy short-circuit current flows which may damage the machine.

**210.** It may be useful to remember that three-phase generators and synchronous motors with stator armatures have two slip rings supplied with D.C.; wound rotor induction motors have three slip rings, and squirrel-cage induction motors have no slip rings.

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* Synchronous motors are sometimes started by connecting them directly to the mains. The eddy currents induced in their field systems and in copper grids fitted in slots in the pole faces being sufficient to run them up to speed, as induction motors, on no load. This involves taking a very large current from the mains, and for machines of large size, auto-transformers (para. 290) are employed to reduce the voltage applied to the stator windings on starting.

# CHAPTER V.

## ALTERNATING CURRENT.

**211.** In the preceding chapter we saw that electric currents are generated in two different forms, viz., direct current and alternating current.

The former is generated by means of a D.C. dynamo, and the latter for W/T purposes by means of a (motor) alternator or a rotary converter.

In this chapter we are particularly concerned with the latter—alternating current—and its behaviour under various conditions.

**212. High and Low Frequencies.**—So far we have been speaking of alternating current as being produced by an alternator, and its frequency as depending upon the number of poles of the alternator and its speed of revolution.

Such currents are spoken of as being "**low-frequency**" or "**audio-frequency**" **currents.**

In wireless telegraphy we meet with alternating currents ranging from, say, 10,000 cycles per second, up to, say, twenty to thirty million per second, produced by means of transmitting arcs and transmitting or receiving valves, by methods which will be described later.

Such currents are spoken of as being "**high frequency,**" "**radio-frequency**" or "oscillatory" currents. The division between high and low frequency currents is not at all sharply defined, and both kinds obey exactly the same laws, if we assume that they follow, or approximate to, the Sine Law.

In Chapter VII., a method of producing a high frequency oscillation by means of a "spark oscillator" is described. The high frequency current there described is slightly different in form, since it starts at a maximum amplitude and dies away to zero, but it also obeys the laws laid down in this chapter.

For our immediate purpose, then, we will consider that we can obtain currents at any frequency we like, without explaining how they are produced in practice.

In diagrams, the source of alternating current will be indicated thus (Fig. 108) which indicates "a source of alternating E.M.F. of any required frequency."

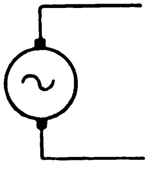


FIG. 108.

**213. Measurement of Alternating Current.**—In measuring the value of an alternating current, it is not convenient to measure its **maximum** value—*i.e.*, the value it reaches at the top of each half cycle of the current curve.

If an alternating current were passed through a moving coil instrument (ammeter or voltmeter) the coil and pointer would be given impulses, many times a second, in either direction, and would not be able to respond to these rapid impulses; consequently the pointer would remain stationary.

The value of any current may, however, be measured by its heating effect upon a conductor of given resistance, and therefore a hot wire ammeter (described in Chapter II., para. **95**) is suitable for our purpose.

The alternating current is continually varying very rapidly in value, and in every cycle (or half or quarter cycle) a certain average heating effect is produced in the bridge wire of the hot wire ammeter; this produces a certain rise of temperature and a corresponding expansion of the wire.

It is obvious that the scale reading obtained will be somewhere between zero and the maximum value of the current; in fact, what we read is the effective or virtual value.

Let us call this effective current I.

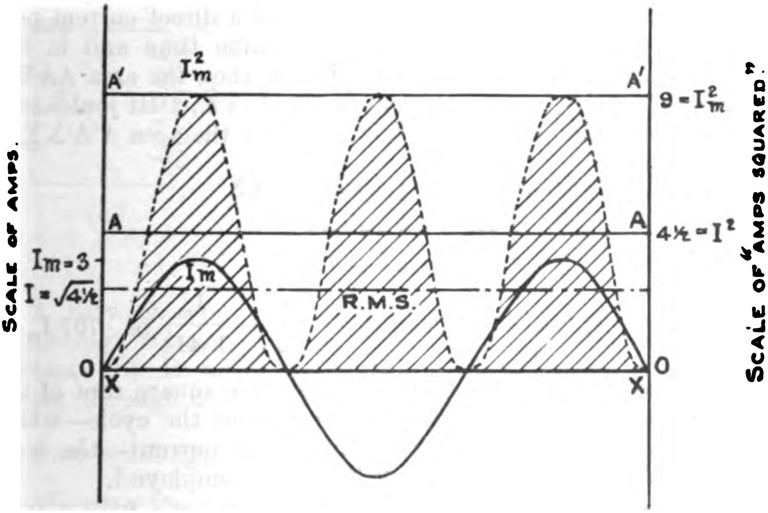


Fig. 109.

Now the power expended in producing heat by a current of I ampères in a resistance of R ohms is $I^2R$ watts, *i.e.*, its heating effect varies as the square of its value.

In Fig. 109 is drawn a curve showing an alternating current rising to a **maximum** value $I_m$ of 3 ampères in each half-cycle.

Let us square the instantaneous values of the alternating current in the cycle.

This will give a curve as shown by the dotted line marked "$I_m^2$."

This curve is entirely positive, as all the positive and all the negative instantaneous values of the current when squared give positive quantities.

The area enclosed by this curve ($I_m^2$) represents the heat produced by one and a half cycles, that is, the sum of the heating effects produced by all the instantaneous values of the alternating current.

This curve will rise to a maximum value of $3^2 = 9$.

In the same way, the heating effect of a **steady** current of 3 ampères is shown by the total area under the straight line A′A′.

It is easily seen that the shaded area is **exactly half** the total area A′A′XX.

Also, if the line AA is drawn mid-way between XX and the peak $I_m^2$, the area AAXX = $\frac{1}{2}$ the area A′A′XX = the shaded area.

If the length of the abscissa XX represents t seconds, and the resistance R is taken as unity, the area A′A′XX = $I_m^2 Rt$ joules (heat energy).

As the effective value (I) is the value of a direct current producing the same heating effect, in the same time and in the same resistance, as the alternating current, then the area AAXX will represent the heating effect due to I, *i.e.*, $I^2Rt$ joules (the same as the shaded area), and this is half of the area A′A′XX.

$$\begin{aligned} \text{Area AAXX} &= \tfrac{1}{2}\text{ area A'A'XX} \\ I^2Rt &= \tfrac{1}{2} I_m^2 Rt \\ I^2 &= \tfrac{1}{2} I_m^2. \end{aligned}$$

$$\text{Therefore I (the effective value)} = \frac{I_m}{\sqrt{2}} = \frac{I_m}{1 \cdot 414} \text{ or } \cdot 707\ I_m.$$

Since the effective current is given by the square root of the average work done by the current throughout the cycle—which depends on the square of the instantaneous current—the term "**Root Mean Square**" or "**R.M.S.**" value is employed.

The value of I is represented in Fig. 109 by the line marked "R.M.S." value.

So that we have two ways of describing an alternating current—

(*a*) By its maximum value,

(*b*) By its R.M.S., Effective, or Virtual Value.

The R.M.S. value (I) of the current can be found by multiplying its maximum value $I_m$ by ·707,

$$i.e., I = \frac{I_m}{\sqrt{2}} = I_m \times \cdot 707, \text{ and } I_m = I \times \sqrt{2} = I \times 1 \cdot 414.$$

In the same way we talk about maximum and R.M.S. values of alternating voltages, which are found in the same manner.

A voltmeter or ammeter measures R.M.S. values only.

For example, if an A.C. voltmeter is reading 200 volts we know that the voltage is rising and falling between zero and maximum value of $200 \times 1 \cdot 414 = 282 \cdot 8$ volts.

For power calculations and for finding the sizes of cables necessary to carry currents we are concerned with R.M.S. values of current and voltage; while for determining the thickness of insulation necessary, the strength of a dielectric or the instant at which a spark gap breaks down, we are concerned with maximum values of voltage.

Remember that in any calculations where current and voltage are interdependent, if we start with a maximum value of voltage the answer will be given as a maximum value of current, and vice versâ.

### 214. Effect of Resistance in an Alternating Current Circuit.

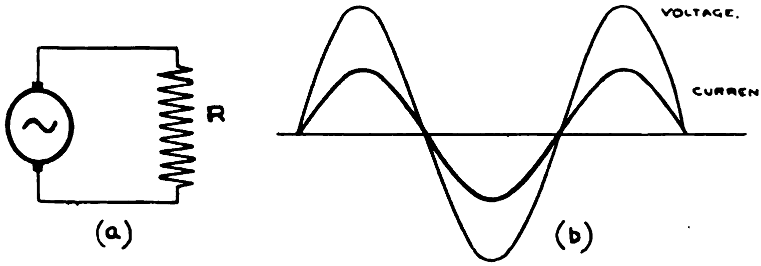


Fig. 110.

If between the slip rings of an alternator, giving an alternating voltage of sine form and $V_m$ volts we join a resistance of R ohms, as in Fig. 110 (*a*), then the current flowing through the circuit (neglecting any inductance of the armature winding) will be equal to $\frac{v}{R}$ ampères at any instant t seconds after the commencement of the cycle.

The maximum value will be $\frac{V_m}{R}$ ampères.

The instantaneous value will be

$$I_t = i = I_m \sin \omega t. \quad (\textit{See} \text{ Ch. IV., para. } \mathbf{149}.)$$

$$= \frac{V_m}{R} \sin \omega t.$$

The current and voltage rise and fall simultaneously as illustrated in Fig. 110 (*b*); they are then said to be "in phase" with one another.

The thin curve represents the voltage, drawn to a scale of volts, and the thick curve the current drawn to a scale of ampères.

**215. Effect of Inductance on an Alternating Current.**—We will now discuss the effect of inductance in an alternating current circuit.

Let us first recall what we have already learnt about the effects of inductance.

If current is switched on to an inductance, the inductance sets up a counter E.M.F. which opposes the rise of the current.

When the current is switched off, the inductance sets up a counter E.M.F., which tends to make the current continue flowing.

Hence the counter E.M.F. **opposes the rise** and **opposes the fall** of a current.

The reason for this action is that as the current increases through the coil, a magnetic field is set up round it, and work has to be done on the coil in order to create this magnetic field.

When the current is stopping, the magnetic field ceases to be maintained by the current, and the energy that was stored in the magnetic field is restored to the circuit.

The unit of inductance is the **Henry,** which is the inductance of a coil of such a form that when the current through the coil is increasing or decreasing at the rate of one ampère per second, the induced E.M.F. or counter E.M.F. is equal to 1 volt.

**216. Rate of Change.**—It follows from the above that what we are concerned with is the **rate of change of the current;** when the current is changing fastest the greatest counter E.M.F. will be induced, and when it is not changing at all there will be no counter E.M.F. induced.

Let us join up a coil (L), which is supposed to have inductance without resistance, to a source of alternating E.M.F., as shown in Fig. 111, and assume that an alternating current is flowing through the inductance as shown in Fig. 112 (*a*).

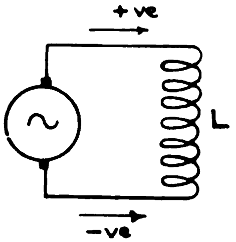


FIG. 111

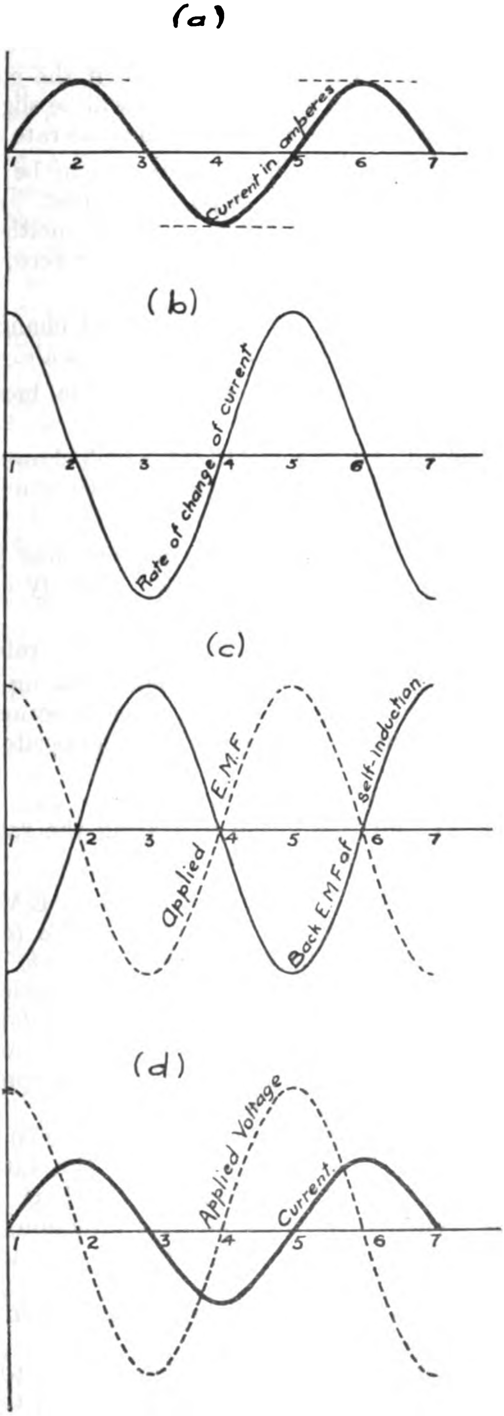

(a)
1
2
3
4
5
6
7
Current in amperes
(b)
1
2
3
4
5
6
7
Rate of change of current
(c)
1
2
3
4
5
6
7
Applied E.M.F
Back E.M.F of Self-Induction.
(d)
1
2
3
4
5
6
7
Applied Voltage
Current.

FIG. 112.

Fig. 112 (*a*) shows a curve where time is plotted horizontally and current strength vertically; hence if the current makes a big change in a short time, the slope of the curve during that period will be steep. On the other hand, if the current makes but little change in a long time, the slope will be slight; thus the slope of the current curve is an indication of its rate of change.

From an inspection of Fig. 112 (*a*) it can be seen that at moments 1, 3, 5, and 7 the slope is steepest. At moments 2, 4 and 6 the current is not changing at all—neither increasing nor decreasing—and the **slope** of the curve is zero, as indicated by the dotted line.

Fig. 112 (*b*) is a curve giving the **rate of change of current** in ampères per second, drawn to any suitable scale.

At moment 1, Fig. 112 (*a*), the current is increasing very rapidly in a positive direction.

This is indicated at 1 in Fig. 112 (*b*), which shows a maximum rate of change in a **positive** direction (above the line) at this moment.

At moment 2, Fig. 112 (*a*), the current has just stopped increasing and is just going to decrease. Exactly on the top of the curve it is not changing at all.

This is indicated at 2, Fig. 112 (*b*), *i.e.*, zero rate of change.

At moment 3, Fig. 112 (*a*), the current is falling very rapidly to zero, and rising very rapidly in the other direction. That is, the current is changing very rapidly in the opposite direction to that at moment 1.

This is indicated at 3, Fig. 112 (*b*); and so on.

Hence Fig. 112 (*b*) is a curve indicating the rate of change of the current shown in Fig. 112 (*a*).

**217. Counter E.M.F.**—Since the counter E.M.F. of any inductance, through which the current of curve (*a*) is flowing, depends on the rate of change of that current, this counter E.M.F. will rise and fall in time with curve (*b*), being maximum when curve (*b*) is maximum, and zero when curve (*b*) is zero.

As regards its direction—positive or negative—we can easily determine that by remembering that it always opposes the rise and fall of current through the inductance.

In curve (*c*) the full line curve represents this counter E.M.F.

At moment 1 it is maximum because the rate of change of the current (curve (*b*)) is maximum, and as the current (curve (*a*)) is trying to rise in a positive direction, the counter E.M.F. is acting in a negative direction trying to prevent it from rising.

At moment 2 the rate of change of the current is zero, so the counter E.M.F. is zero also.

Between moments 2 and 3 the current wants to fall, so the counter E.M.F. acts in the opposite direction to that in which it was acting between moments 1 and 2.

Between moments 3 and 4 the current is trying to rise in a negative direction. Therefore the counter E.M.F. acts in a positive direction trying to prevent it from rising; and so on.

Hence curve (*c*) shows the relative strength and direction of the counter E.M.F. of self induction at any instant.

**218. Applied E.M.F.**—If the counter E.M.F. had its own way it would prevent the current from rising and falling at all.

In order, therefore, to make the current flow through the inductance, the source of alternating current has to apply a voltage which is equal and opposite to the counter E.M.F.; that is to say, a voltage which is equal to the counter E.M.F. at any instant, and is acting in a positive direction when the counter E.M.F. is acting in a negative direction, is zero when the counter E.M.F. is zero, and is maximum negative when the counter E.M.F. is maximum positive.

The applied voltage from the source of alternating current, then, will be as shown by the dotted curve shown in Fig. 112 (*c*). It can be seen at once that this voltage is equal in magnitude and opposite in direction to the counter E.M.F. at any instant.

In addition, a small voltage will be required from the supply source to overcome the small resistance which must be present in the coil. But as the latter has been supposed to be negligible, we will neglect this small additional voltage for the present.

Fig. 112 (*d*) shows the combination of curves (*a*) and (*c*). That is to say, it shows the voltage applied by the alternating source and the resulting alternating current flowing through the inductance L.

From this diagram it can be seen that in a circuit containing nothing but inductance, the current and voltage do not rise and fall together, as was shown in Fig. 110 (*b*), but the current always comes to its maximum value a quarter cycle later than the alternating voltage.

When current and voltage rise and fall together, as in Fig. 110 (*b*), they are said to be " in phase."

When they do not rise and fall together, they are said to be " out of phase."

When the alternating current reaches its maximum value after the applied voltage, as in Fig. 111 (*d*), the current is said to **lag** behind the voltage.

Conversely, when it reaches its maximum **before** the applied voltage, it is said to be a **leading** current.

**219.** An almost parallel example is given by the flow of water into and out of harbour. Let us call the level of water in a harbour at half tide the normal or zero value, and the level at lowest ebb the maximum negative value.

At the top of the flood and at lowest ebb the level of water in the harbour is maximum positive or maximum negative; at these moments the flow of water into or out of harbour is zero.

At half-tide—the moment of normal or zero level of water in the harbour—the ebb or flow current is maximum.

Thus curves representing these two variables—the current at the mouth of the harbour, and the level of water in the harbour—would be a quarter of a cycle out of phase, and just like Fig. 112 (*d*).

**220. Vector Diagrams.**—Now the various curves shown in Fig. 112 are not too easy to follow, or to draw correctly. Their maximum values may be readily represented by the use of "Vector Diagrams."

A Vector quantity is one which has magnitude and direction, *e.g.*, a voltage, current, force, &c.

Any of these may be represented by a straight line whose length represents the magnitude of the quantity, and whose direction represents the direction of the quantity at the moment illustrated.

Moreover, these vectors may be considered as revolving, usually in a counter-clockwise direction, to indicate a quantity which is varying periodically, so that the idea of phase difference (lag or lead) may be indicated.

Thus, if we wish to represent two sine curves, as in Fig 112 (*d*), each of these two curves may be indicated by one of two straight lines, the angle between which will indicate the relative phase difference between the two sine curves.

For example, the curves shown in Fig. 112 may be represented by the following vector diagrams :—

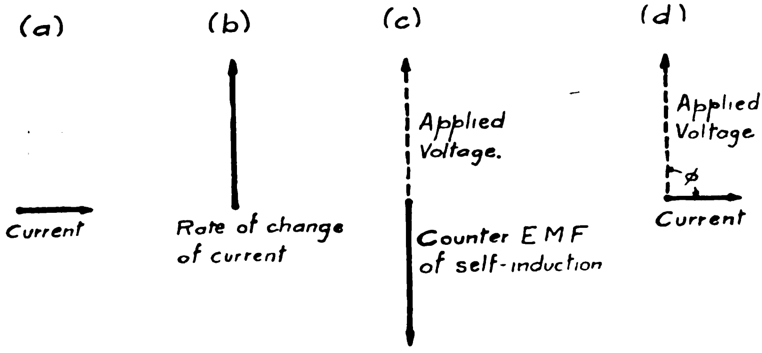


FIG. 113.

Fig. 113 (*d*) is a vector diagram showing the applied voltage and resultant current flowing in a circuit containing nothing but inductance.

This shows that current and voltage are out of phase by an angle $\phi$ which here equals 90°; the current lagging behind the applied voltage. Thus the maximum values of the sine curves can be represented by vectors, bringing out very clearly the idea of phase relationship; instantaneous values, however, cannot be read from a diagram : they are given by the vertical components of the vectors as they rotate.

**221. Value of Back E.M.F. of Self Induction.**—We have already learnt in Chapter III. that the induced E.M.F. across an inductance of L henries is equal in volts to $-$ L × rate of change of current in ampères per second.

From Fig. 112 (*b*) it can be seen that this rate of change of current is a quantity varying between maximum and zero.

The maximum rate of change of a current which reaches a maximum value of $I_m$ ampères, in an armature bar revolving with an angular velocity of $2\pi f$ radians per second is **$2\pi f I_m$ ampères per second or $\omega I_m$** (where $\omega = 2\pi f$, *see* para. **148**).

(The proof of this is as follows, but is not important for our purposes :—

$$i = I_m \sin \omega t \text{ (para. 149)}.$$

The rate of change of $i$ at any moment =

$$\frac{di}{dt} = \omega I_m \cos \omega t,$$

and, as the maximum value of the cosine of any angle = 1, the maximum value of the rate of change is $2\pi f I_m$.)

Hence the value of the induced E.M.F. in an inductance of L henries when traversed by an alternating current of a value of I ampères is

$$\begin{aligned} &- L \times 2\pi f I \text{ volts} \\ &= -\, 2\pi f L I \text{ volts} \\ &= -\, \omega L I \text{ volts.} \end{aligned}$$

The negative sign only means that the induced E.M.F. is in opposition to the rise and fall of the current.

Hence if a voltage of V volts is applied to an inductance of L henries at a frequency of " f " cycles per second, the resulting current flowing will be

$$I = \frac{V}{2\pi f L} \text{ ampères} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Resistance or rather conductivity—(*i.e.*, free electrons)—must be present to carry the current.

Hence a small additional voltage above $\omega LI$ is necessary and it is this that actually drives the current.

In this section, however, it is assumed that this voltage is so small compared to the $\omega LI$ voltage that it may be neglected.

This is our new " Ohm's Law " for alternating current circuits where inductance only is present.

The expression $\omega L$ takes the place of R, and has the same effect of cutting down the current flowing. As, however, the energy expended in creating the magnetic field round an inductance is restored when the magnetic field collapses, there is no expenditure of energy involved in the introduction of an inductance into a circuit, in the same way as there would be were resistance introduced.

$$\text{As } V = \omega L I$$

$$\omega L = \frac{V}{I} = \frac{\text{volts}}{\text{amps}} = \text{ohms.}$$

The expression $\omega L$ "ohms" is convenient in calculations. It does not represent ohms in the sense of true ohmic resistance, but is used for mathematical purposes.

It is denoted by the symbol "$X_L$," and is termed "**Inductive Reactance.**"

### Example 24.

Find the value of the current flowing through an inductance of ·5 henry, of negligible resistance, if an alternating voltage of 200 volts is applied at a frequency of 50 cycles.

$$I = \frac{V}{2\pi fL} = \frac{200}{2 \times 3{\cdot}14 \times 50 \times {\cdot}5} = \frac{4}{3{\cdot}14} = 1{\cdot}27 \text{ amps.}$$

### Example 25.

Find the value of the current flowing through an inductance of 200 mics, with an applied voltage of 1,000 volts at a frequency of 500,000 cycles.

$$200 \text{ mics} = \frac{200}{10^6} \text{ henries.}$$

$$X_L = \omega L = 6{\cdot}28 \times 500{,}000 \times \frac{200}{10^6} = 6{\cdot}28 \times 5 \times 10^5 \times \frac{200}{10^6}$$

$$= 628 \text{ ohms.}$$

$$I = \frac{V}{X_L} = \frac{1000}{628} = 1{\cdot}6 \text{ ampères.}$$

**222. Inductances in parallel.**—If two inductances $L_1$ and $L_2$ are joined in parallel, and an alternating voltage (V) is applied to them (Fig. 114), then currents of $I_1 = \frac{V}{\omega L_1}$ and $I_2 = \frac{V}{\omega L_2}$ will flow through them respectively.

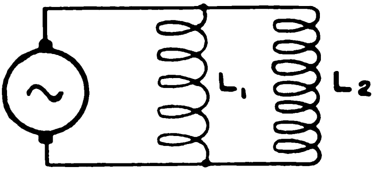


FIG. 114.

As each of these currents is lagging by 90° on the applied voltage V, they will be in phase with one another and the resultant current will be the sum of the two :—

$$i.e., I = I_1 + I_2 = \frac{V}{\omega L_1} + \frac{V}{\omega L_2} = \frac{V}{\omega}\left\{\frac{1}{L_1} + \frac{1}{L_2}\right\}$$

If the resultant current only is required, it can be found more easily in the following manner: if L is the joint inductance of two inductances $L_1$ and $L_2$,

$$\text{then } \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} \text{ or } L = \frac{L_1 \times L_2}{L_1 + L_2}.$$

$$\text{Then } I = \frac{V}{\omega L} \text{ where } L = \frac{L_1 \times L_2}{L_1 + L_2}$$

**223. Effect of Inductance and Resistance.**—So far, we have only considered two cases :—

(*a*) Where the circuit contains nothing but **resistance.**

Here $I = \frac{V}{R}$, and current and voltage are in phase.

(*b*) Where the circuit contains nothing but **inductance.**

Here $I = \frac{V}{\omega L}$, and the current lags 90° behind the applied voltage.

Now, although in practice we often get cases where the inductance is so small compared with the resistance, or the resistance is so small compared to the inductance, that the smaller item can be neglected, yet, as a rule, we have to consider both the inductance and the resistance of the circuit.

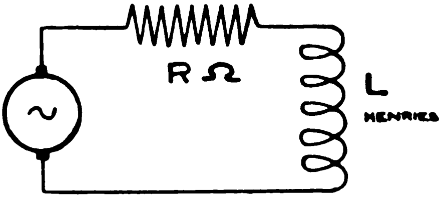


Fig. 115.

In the case shown in Fig. 115, the applied voltage has to do two things :—

(1) Overcome the IR drop in the circuit.

(2) Overcome the counter E.M.F. of the inductance of L henries.

So that the whole of the impressed volts are not available for forcing current through the resistance.

The presence of inductance restricts the value of the current and we cannot use Ohm's Law alone.

Fig. 116 (*b*) shows the conditions under these circumstances.

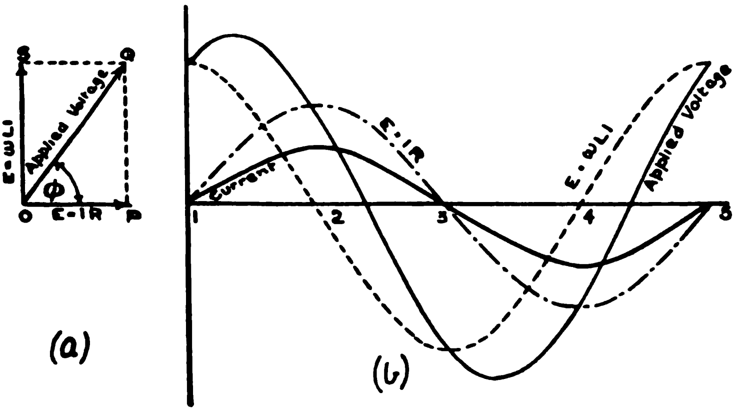


Fig. 116.

The thick line curve indicates the rise and fall of the current.

The voltage forcing the current through the resistance R is indicated by the curve "**E = IR.**"

It is in phase with the current.

The voltage overcoming the counter E.M.F. of the inductance L is indicated by the curve "**E = $\omega$LI,**" which is 90° out of phase with and leading the current.

The total voltage required from the alternator in order to supply these two voltages simultaneously can be found by adding the ordinates of the two curves together at every instant, taking account of their directions; the result is shown by the curve marked "**Applied Voltage.**"

It will be seen that—

(*a*) At moment 1 the IR curve is zero, and the $\omega$LI curve is maximum, so that the "applied voltage" required = $\omega$LI only.

(*b*) At moment 2 the IR curve is maximum and the $\omega$LI curve is zero, so that the applied voltage required = IR only.

(*c*) Between moments 1 and 2 both the IR and $\omega$LI curves are positive.

(*d*) Between moments 2 and 3 the $\omega$LI curve is increasing in a negative direction, while the IR curve is decreasing, but is still positive: hence the resultant curve is found by subtracting the ordinates of the $\omega$LI curve from those of the IR curve.

(*e*) Between moments 3 and 4 the IR curve and the $\omega$LI curve are both negative; hence their ordinates must be added to find the resultant.

It will be seen by comparing maximum positive values that the current is lagging behind the applied voltage by some angle less than 90°.

**224. Value of Applied Voltage.**—The required value of the applied voltage to make a current of I ampères flow through the resistance R and the inductance L can be readily determined from a vector diagram showing the maximum values of the IR curve and the $\omega$LI curve.

The maximum value of the IR curve is indicated in Fig. 116 (*a*) by the vector marked "E = IR" (which is 7 units long); this vector is equal in length to the maximum height of the IR curve, and is drawn horizontally to the right because the IR curve starts at zero and rises.

Similarly the $\omega$LI curve is shown by the vector E = $\omega$LI (which is 10 units long); this vector is equal in length to the maximum height of the $\omega$LI curve, and is drawn vertically upwards because the $\omega$LI curve leads on the current curve by 90° or a ¼ cycle.

The voltage which will be equal to the combined effect of these two voltages—"E=IR" and "E=$\omega$LI"—can be found by completing the parallelogram OPQS and drawing the diagonal OQ.

This vector OQ gives the applied voltage required.

Its length indicates the maximum value of the "Applied Voltage" curve, and the angle $\phi$ indicates the phase angle by which the current curve—in phase with the IR curve—lags behind the applied voltage curve.

It will be noticed that the length of the line OQ (12·2 units long) is equal to the maximum height to which the "Applied Voltage" curve rises, and the line QP—the vertical height of the point Q above the horizontal—is equal to the vector OS, since at the moment taken the IR curve is zero.

The value of the applied voltage in terms of the IR and $\omega$LI vectors can be found as follows :—

We know that in any right-angled triangle the square on the hypotenuse equals the sum of the squares on the other two sides.

Hence :—$(OQ)^2 = (OP)^2 + (PQ)^2$,
but $PQ = OS$,
therefore $OQ = \sqrt{(OP)^2 + (OS)^2}$,
but OP represents IR and
OS represents $\omega LI$.

Therefore the maximum value of the applied voltage must be equal to $\sqrt{(IR)^2 + (\omega LI)^2}$.

$$\textbf{Therefore } \mathbf{V = I\sqrt{R^2 + (\omega L)^2}}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2)}$$

$$\textbf{or } \mathbf{I = \frac{V}{\sqrt{R^2 + (\omega L)^2}}}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3)}$$

This is "Ohm's Law" for A.C. circuits containing inductance and resistance.

The expression $\sqrt{R^2 + (\omega L)^2}$ is called the "**Impedance**" of the circuit and is denoted by the letter **Z (ohms)**.

Notice that :—

(*a*) $\frac{PQ}{OQ} = \sin\phi$ : hence $PQ = OQ \sin\phi$.

(*b*) $\frac{OP}{OQ} = \cos\phi$ : hence $OP = OQ \cos\phi$.

(*c*) $\frac{PQ}{OP} = \tan\phi$ : hence $PQ = OP \tan\phi$.

Hence the reactive drop $= \omega LI = V \sin\phi$ from (*a*), and the ohmic drop $= IR = V \cos\phi$ from (*b*).

Also the angle $\phi$ is an angle whose tangent is :—

$$\frac{\omega LI}{IR} = \frac{X_L}{R} = \frac{\text{Reactance}}{\text{Resistance}}.$$

**Example 26.**

Let an alternating voltage of 100 volts at a frequency of 25 cycles per second be applied to a circuit of resistance 1·5 ohms. and of inductance ·01 henry. Find (*a*) the current flowing, and (*b*) the angle of lag :—

(*a*) $\omega = 2\pi f = 2\pi \times 25 = 50\pi = 157$ radians per sec.

Reactance $= X_L = \omega L = 157 \times \cdot 01 = 1\cdot 57$ ohms.

Resistance $= 1\cdot 5$ ohms.

Impedance $Z = \sqrt{R^2 + X_L^2} = \sqrt{1\cdot 5^2 + 1\cdot 57^2} =$

$$\sqrt{2\cdot 25 + 2\cdot 46} = \sqrt{4\cdot 71} = 2\cdot 17 \text{ ohms.}$$

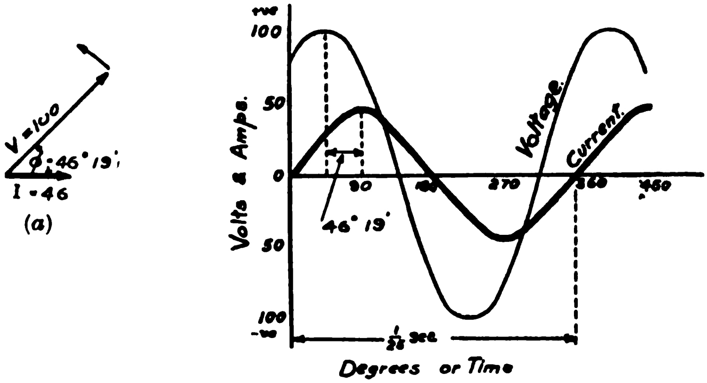
$$I = \frac{V}{Z} = \frac{100}{2\cdot 17} = 46 \text{ ampères.}$$

$$(b)\ \operatorname{Tan} \phi = \frac{X_L}{R} = \frac{1\cdot 57}{1\cdot 5} = 1\cdot 047.$$

From a table of Tangents (page 534) $\phi$ is seen to be an angle of 46° 19′.

So we have a current of 46 amps. lagging 46° or ·13 of a cycle behind the E.M.F. of 100 volts.

Plotting these as vectors and as curves, we get Fig. 117 (*a*) and (*b*).



(*a*)

(*b*)

FIG. 117.

The voltage drop in the resistance

$$= IR = 46 \times 1\cdot 5 = 69 \text{ volts.}$$

The voltage balancing the counter E.M.F. of the inductance

$$= \omega LI = 1\cdot 57 \times 46 = 72\cdot 2 \text{ volts.}$$

It seems impossible for the 100 applied volts to supply both these values, but remember that the reactive and resistance drops have not got to have their maximum wants supplied simultaneously.

Let us take a high frequency example.

### Example 27.

Let a pressure of 100 volts at a frequency of 10,000 cycles per second be applied to a circuit of resistance 20 ohms and inductance 300 mics. Find (*a*) the current flowing, and (*b*) the angle of lag.

$$\omega = 2\pi \times 10{,}000 = 6\cdot 28 \times 10^4.$$

$$X_L = \omega L = 6\cdot 28 \times 10^4 \times \frac{300}{10^6*} = 6\cdot 28 \times 3 = 18\cdot 84 \text{ ohms.}$$

---

* Remember in any example involving millihenries or microhenries, to convert them into henries by dividing by $10^3$ and $10^6$ respectively.

$$R = 20 \text{ ohms.}$$
$$Z = \sqrt{20^2 + 18\cdot84^2} = \sqrt{400 + 355} = \sqrt{755} = 27\cdot48 \text{ ohms.}$$
$$I = \frac{V}{Z} = \frac{100}{27\cdot48} = 3\cdot64 \text{ amps.}$$
$$IR = 3\cdot64 \times 20 = 72\cdot8 \text{ volts.}$$
$$\omega LI = 3\cdot64 \times 18\cdot84 = 68\cdot6 \text{ volts.}$$
$$(b)\ \tan\phi = \frac{18\cdot84}{20} = \cdot942. \quad \phi = 43^\circ\ 15'.$$

Let us try the effect of applying the high frequency voltage of Example 27 to the circuit given in Example 26.

**Example 28.**

$$\text{As before, } \omega = 2\pi \times 10^4.$$
$$X_L = \omega L = 2\pi \times 10^4 \times \cdot01 = 6\cdot28 \times 10^2 = 628 \text{ ohms.}$$
$$R = 1\cdot5 \text{ ohms.}$$
$$Z = \sqrt{1\cdot5^2 + 628^2} = 628 \text{ ohms practically.}$$
$$I = \frac{V}{Z} = \frac{100}{628} = \cdot163 \text{ amps.}$$
$$\tan\phi = \frac{628}{1\cdot5} = 418. \quad \phi = 89^\circ\ 52' = 90^\circ \text{ practically.}$$

From this example we may deduce that with a high frequency voltage applied to a circuit where the inductance is great compared with the resistance, the resulting current depends practically entirely upon the value of the inductance and is practically 90° out of phase with the applied voltage.

**225. Inductance and Resistance in Parallel.**—If an inductance and resistance are joined in parallel (as in Fig. 118 (*a*)), and an alternating voltage (V) is applied to the combination, then—

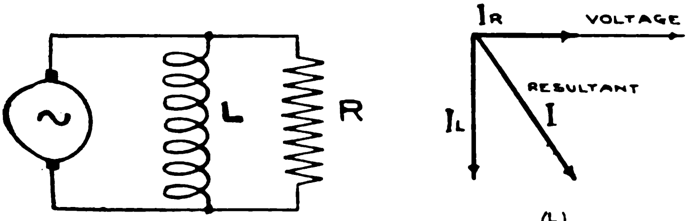
(*a*) a current $I_L$ will flow through the inductance, equal to $\frac{V}{\omega L}$ and lagging by 90° on the applied voltage.

(*b*) a current ($I_R$) will flow through the resistance equal to $\frac{V}{R}$, in phase with the applied voltage.

The resultant current required from the alternating supply can be found by means of a vector diagram, as shown in Fig. 118 (*b*).

It will be equal to:— $\sqrt{I_R^2 + I_L^2}$

$$= \sqrt{\left(\frac{V}{R}\right)^2 + \left(\frac{V}{\omega L}\right)^2}$$



(a) (b)

FIG. 118.

**Example 29.**

An alternating voltage of 100 volts at a frequency of 10,000 cycles per second is applied to a circuit consisting of a resistance of 20 ohms in parallel with an inductance of 300 mics. Find (*a*) the current and (*b*) the angle of lag.

$$\omega = 2\pi \times 10{,}000 = 6{\cdot}28 \times 10^4.$$

$$X_L = \omega L = 6{\cdot}28 \times 10^4 \times \frac{300}{10^6} = 6{\cdot}28 \times 3 = 18{\cdot}84 \text{ ohms.}$$

$$I_L = \frac{V}{\omega L} = \frac{100}{18{\cdot}84} = 5{\cdot}31 \text{ amps.}$$

$$I_R = \frac{V}{R} = \frac{100}{20} = 5 \text{ amps.}$$

$$\text{Resultant current} = \sqrt{I_R^2 + I_L^2} = \sqrt{5^2 + 5{\cdot}31^2}$$

$$= \sqrt{25 + 28{\cdot}17} = \sqrt{53{\cdot}17} = 7{\cdot}3 \text{ amps.}$$

$$\tan\phi = \frac{I_L}{I_R} = \frac{5{\cdot}31}{5} = 1{\cdot}06. \quad \phi = 46^\circ\ 42'.$$

Hence the resultant current is one of 7·3 ampères lagging behind the applied voltage by an angle of 46° 42′.

**226.** The following rule for drawing vector diagrams may be found useful :—

**In series circuits**—inductance, resistance, &c., in series—the current through each will be the same, and the voltage drop across each will be different. **Start by drawing the current line.** Lay off along it the voltage drop due to resistance, and the voltage drop due to reactance at right angles.

**In parallel circuits**—inductance, resistance, &c., in parallel—the voltage applied to each will be the same, and the current through each will be different. **Start by drawing the voltage line.** Lay off along it the current through the resistance, and the current through the inductance at right angles.

**227. Effect of Capacity on an Alternating Current.**—The effect of a condenser joined alone in an A.C. circuit is exactly opposite to that of an inductance.

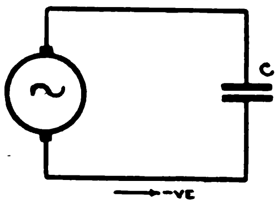


FIG. 119

Let us now suppose a condenser (C) is joined to our alternating current source, as illustrated in Fig. 119. We wish to determine what its effect will be on the alternating current.

We have already learnt in Chapter III. that the capacity of a condenser is its power of storing up electrical energy, and that this capacity depends upon the area of its plates, the thickness of the dielectric used, and the nature of the substance used as a dielectric;

That the unit of capacity is the **Farad**, which is the capacity of a condenser of such a size that a charge of one coulomb introduced into it will produce a D.P. between its plates of one volt;

And that the formula $Q = CV$ is true; *i.e.*, that the charge introduced (in coulombs) is equal to the capacity of the condenser (in Farads) multiplied by the pressure applied (in volts).

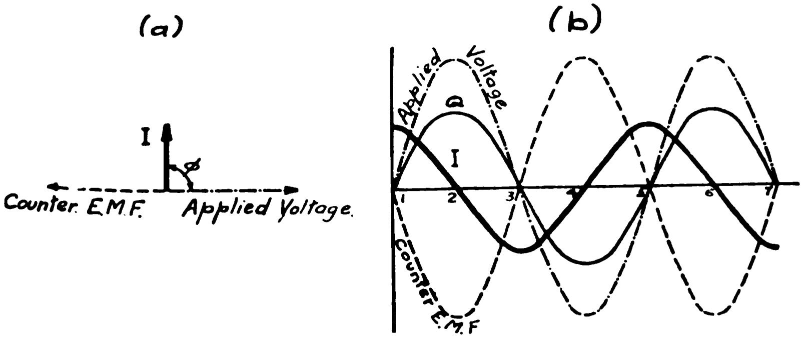


FIG. 120.

**228.** In considering the effect of capacity, it is very important to distinguish between the **quantity**, or charge introduced into the condenser (measured in coulombs) and the **current**, or **rate** at which these coulombs are flowing into the condenser (measured in "coulombs per second" or "ampères").

The reader will find it very useful here to consider again the analogy of the water in the harbour given in para. **219**, and to draw curves for himself of the current and the quantity of water in the harbour. They will be found to correspond exactly with the curves marked "Q" and "I" in the above diagram.

Let us consider the effect of the alternating voltage (as shown by the curve marked "applied voltage" (Fig. 120 (*b*) ) when applied to the condenser shown in Fig. 119.

As this voltage rises in a positive direction (between moments 1 and 2) a greater and greater charge of electricity will be introduced into the condenser, till at moment 2 a maximum charge (as shown by the curve marked "Q") has been introduced.

Due to the introduction of this charge, a counter E.M.F. is set up across the condenser, equal to $\frac{Q}{C}$ volts, which is exactly equal to the applied voltage at each instant. (This E.M.F. is indicated by the curve marked "Counter E.M.F.").

Then between moments 2 and 3, as the applied voltage decreases, the counter E.M.F. forces the charge out of the condenser again, till at moment 3, when the applied voltage is zero, no charge is left in the condenser.

After moment 3, when the applied voltage rises in the opposite direction, electricity starts to flow into the condenser in the opposite direction, and so on.

Now the **current curve** indicates the **rate of flow** of electricity into and out of the condenser, and will depend on the steepness of the applied voltage curve and of the curve Q indicating the charge introduced, these two curves being interdependent.

At the moment 1 the applied voltage curve is increasing very rapidly in a positive direction, so the **rate of flow of coulombs**—*i.e.*, **current**—is a maximum in a positive direction.

Between moments 1 and 2, the applied voltage curve rises more and more slowly, till at moment 2 it is steady for an instant.

Therefore the rate of flow, or current, becomes less and less also, and at moment 2 is zero.

Between moments 2 and 3 the coulombs are flowing out of the condenser faster and faster, so the current curve gets greater and greater in a negative direction.

(N.B.—Look at Fig. 119 to see what is meant by a " negative " direction.)

Between moments 3 and 4 electricity flows into the condenser in a negative direction, but more and more slowly as moment 4 is approached.

From this, and by inspecting the " applied voltage " and " current curves " in Fig. 120 we deduce that in a circuit containing nothing but capacity, the current is in advance of, or " leads " the applied voltage by 90°.

**229**. From an inspection of Fig. 120 (*b*) it may also be seen that between moments 1 and 2, when the current is positive and falling, the counter E.M.F. of the condenser is negative and assists it to fall.

Between moments 2 and 3, when the current is rising in a negative direction, the counter E.M.F. is also negative, and therefore assists it to rise.

Between moments 3 and 4, when the current is falling in a negative direction, the counter E.M.F. is acting in a positive direction and assists it to fall.

Hence the counter E.M.F. of a condenser **assists** changes in the direction of a current, and is therefore exactly opposite in its effect to an inductance, which, as we saw in para. **215** above, **opposes** such changes.

**230. Counter E.M.F. of a Condenser.**—The current flowing into a condenser is simply a measure of the **rate of change of the charge introduced.**

Just as the maximum rate of change of an alternating current of I max. ampères was $2\pi f I_m$ ampères per second, so the maximum rate of change of a charge of $Q_m$ coulombs is $2\pi f Q_m$ coulombs per second.

Hence $I_m = 2\pi f Q_m$,

but $Q_m = CV_m$,

**Therefore** $I_m = 2\pi f C V_m$, (4)

**or** $V_m$ **(the counter E.M.F.)** $= \frac{I_m}{2\pi f C} = \frac{I_m}{\omega C}$

(The mathematical proof of this is as follows :—

$v = V_m \sin \omega t$ (applied voltage at any instant).
$q = Q_m \sin \omega t$ (charge in condenser at any instant).
As $Q = CV$ then $q = Cv$.

$$i = \frac{dq}{dt} = \frac{d\,(Q_m \sin \omega t)}{dt} = \omega Q \cos \omega t.$$
$$= \omega CV \cos \omega t \text{ or } \omega CV \sin (\omega t + 90°).$$

(*i.e.* the current leads by 90° on the applied volts.)

Then $I_m = \omega C V_m$, or $V_m = \frac{I_m}{\omega C}$.)

The law for A.C. circuits containing capacity only is therefore $I = \omega CV$ or $V = \frac{I}{\omega C}$.

The expression $\frac{1}{\omega C}$ is termed **Capacitive Reactance,** and is denoted by the symbol $X_C$ **(ohms).**

The vectors expressing applied E.M.F. and resultant current are as shown in Fig. 121.

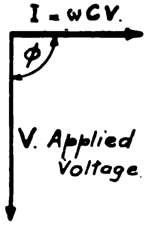


FIG. 121.

### Example 30.

Find the current flowing through[*] a condenser of 45 jars if an alternating voltage of 100 volts is applied at a frequency of 300,000 cycles per second.

$$\omega = 2\pi f = 2\pi \times 300{,}000 = 1{\cdot}884 \times 10^6.$$

$$X_c = \frac{1}{\omega C} = \frac{1}{1{\cdot}884 \times 10^6} \times \frac{9 \times 10^8}{45} \text{ (converting jars to farads)}\dagger = \frac{20}{1{\cdot}884} = 10{\cdot}61 \text{ ohms.}$$

$$I = \frac{100}{10{\cdot}61} = 9{\cdot}4 \text{ ampères.}$$

### 231. Condensers in Parallel and Series.—

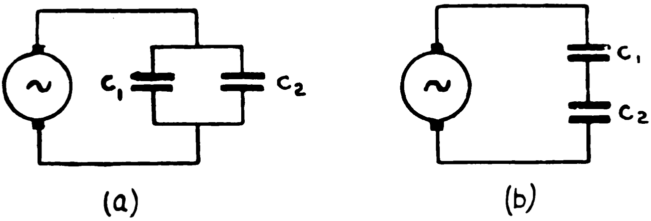


Fig. 122.

**Condensers in Parallel.**—If two condensers, $C_1$ and $C_2$, are joined in parallel, as in Fig. 122 (*a*), then the P.D. across them will be the same, and currents $I_1$ and $I_2$ will flow through $C_1$ and $C_2$ such that $I_1 = \omega C_1 V$ and $I_2 = \omega C_2 V$, if V is the applied voltage.

The total current flowing from the supply will be $I = I_1 + I_2 = \omega C_1 V + \omega C_2 V = \omega V(C_1 + C_2)$.

So that, to find the joint capacity of two (or more) condensers joined in **parallel**, their individual capacities should be added together.

**Condensers in Series.**—If two condensers, $C_1$ and $C_2$, are joined in series, as in Fig. 122 (*b*), then each will have a counter E.M.F. which has to be opposed by the applied E.M.F., and these E.M.F.s will act in the same direction, and should be added together.

These counter E.M.F.'s will be $V_1 = \dfrac{I}{\omega C_1}$ and $V_2 = \dfrac{I}{\omega C_2}$ and their joint effect will be—

$$V = V_1 + V_2 = \frac{I}{\omega C_1} + \frac{I}{\omega C_2} = \frac{I}{\omega}\left(\frac{1}{C_1} + \frac{1}{C_2}\right).$$

---

[*] It is the custom to speak loosely of a current flowing "through" a condenser, when what is meant is a current charging a condenser alternately on either side, or a displacement current flowing in the condenser.

No current actually flows through, but the electrons in the dielectric are strained alternately in each direction.

[†] Readers who are not accustomed to the unit of a "jar" used throughout this book should remember that 1 jar = 1/900th microfarad,
= 1,000 centimetres,
= 10/9ths milli-microfarad.

Thus the joint capacity (C) of two (or more) condensers joined in **series** is such that—

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \text{\&c.}$$

$$\left(\text{or } C = \frac{C_1 \times C_2}{C_1 + C_2} \text{ for two condensers in series}\right).$$

Note that the rule for finding the joint effect of condensers joined in series or parallel is exactly opposite to that for resistances or inductances.

### 232. Circuits containing Inductance, Capacity and Resistance in Series.

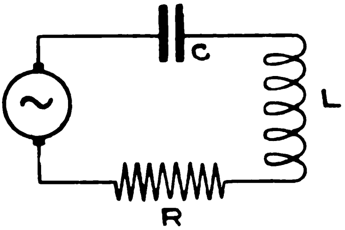


Fig. 123.

We now come to the most important problem of all, and one with which we are perpetually concerned in wireless telegraphy —namely, the case of a circuit containing **inductance, capacity and resistance in series** (as in Fig. 123).

In this case the alternator has three duties to perform; it has to supply—

(*a*) A voltage $E_1$ (= IR) to drive the current through the resistance R.

(*b*) A voltage $E_2$ (= $\omega$LI) to overcome the counter E.M.F. of the inductance L.

(*c*) A voltage $E_3$ $\left(= \frac{I}{\omega C}\right)$ to overcome the counter E.M.F. of the condenser C.

Let us draw a vector diagram of these three voltages, taking due account of their relative phases (Fig. 124).

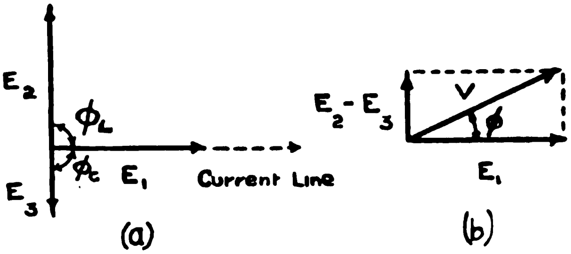


Fig. 124.

The vector $E_1$ (= IR) is in phase with the current;
the vector $E_2$ (= $\omega$LI) is 90° in advance of the current; and
the vector $E_3$ $\left(= \frac{I}{\omega C}\right)$ is 90° behind the current.

As $E_2$ and $E_3$ are exactly opposite in phase, we can obtain their resultant by subtracting the smaller from the greater (in the case illustrated by subtracting $E_3$ from $E_2$).

The problem then becomes the much simpler one of finding the resultant of two vectors—

$$E_1 = IR \text{ and } (E_2 - E_3) = \left(\omega LI - \frac{I}{\omega C}\right) = I\left(\omega L - \frac{I}{\omega C}\right).$$

This is obtained as shown in Fig. 124 (*b*), the resultant applied voltage (V) obviously being such that—

$$V^2 = E^2_1 + (E_2 - E_3)^2 = I^2R^2 + I^2\left(\omega L - \frac{1}{\omega C}\right)^2.$$

$$\text{Therefore } V = I\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}, \tag{5}$$

$$\text{or } \mathbf{I} = \frac{\mathbf{V}}{\sqrt{\mathbf{R}^2 + \left(\omega \mathbf{L} - \frac{1}{\omega \mathbf{C}}\right)^2}}. \tag{6}$$

This is the law for A.C. circuits containing inductance, capacity and resistance in series.

The expression $\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$ is termed the "**Impedance**" of the circuit and is denoted by the symbol **Z (ohms).**

The tangent of the angle ($\phi$) of lag or lead is such that

$$\tan \phi = \frac{I\left(\omega L - \frac{1}{\omega C}\right)}{IR} = \frac{X_L - X_C}{R} = \frac{\text{reactance}}{\text{resistance}}.$$

As the tendency for the current to lag depends on the value of the counter E.M.F. of the inductance ($\omega$LI volts), and the tendency for the current to lead depends on the counter E.M.F. of the condenser $\left(\frac{I}{\omega C} \text{ volts}\right)$ it can be seen that if $\omega$LI is greater than $\frac{I}{\omega C}$ $\left(\text{or } \omega L \text{ is greater than } \frac{1}{\omega C}\right)$, the resultant current will lag behind the applied E.M.F., and *vice versâ*.

The fact of the counter E.M.F.s of the inductance and capacity partially cancelling one another means that the counter E.M.F. of the inductance helps to charge up the condenser, and the counter E.M.F. of the condenser helps to create the magnetic field round the inductance by the current it produces; the assistance of the applied voltage is only required to balance the difference between these two counter E.M.F.s.

A voltmeter, if joined across the inductance, would read $\omega LI$ volts, and if joined across the condenser would read $\frac{I}{\omega C}$ volts, but if joined across the two would read the difference between the two voltages, *i.e.*, $\omega LI - \frac{I}{\omega C}$ volts.

**Example 31.**

An alternating voltage of 50 volts at a frequency of 158,000 cycles per second is applied to a circuit consisting of an inductance of 900 mics, a condenser of 1 jar, and a resistance of 10 ohms.

Find (*a*) the current flowing;
(*b*) the phase angle of lag or lead;
(*c*) the P.D. across the inductance;
(*d*) the P.D. across the condenser.

(*a*) $\omega = 6\cdot28 \times 158{,}000 = 9\cdot924 \times 10^5$.

$X_L = \omega L = 9\cdot924 \times 10^5 \times \frac{900}{10^6} = 893\cdot16$ ohms.

$X_C = \frac{1}{\omega C} = \frac{1}{9\cdot924 \times 10^5} \times \frac{9 \times 10^8}{1} = \frac{9{,}000}{9\cdot924} =$ $906\cdot7$ ohms.

$X_C - X_L = 906\cdot7 - 893\cdot16 = 13\cdot54$ ohms.

$Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{10^2 + 13\cdot54^2} =$ $\sqrt{283\cdot4} = 16\cdot83$ ohms.

$I = \frac{V}{Z} = \frac{50}{16\cdot83} = 2\cdot97$ ampères.

(*b*) $\tan\phi = \frac{X_C - X_L}{R} = \frac{13\cdot54}{10} = 1\cdot354$. $\phi = 53° 35'$.

Since $X_C$ is greater than $X_L$, $\phi$ will be an angle of lead.

(*c*) $\omega LI = X_L I = 893\cdot16 \times 2\cdot97 = 2{,}655$ volts.

(*d*) $\frac{I}{\omega C} = X_C I = 906\cdot7 \times 2\cdot97 = 2{,}694$ volts.

**233. Resonance.**—A question that naturally arises is—cannot we so arrange matters that the counter E.M.F. of the inductance exactly balances the counter E.M.F. of the condenser?

This condition is attained if we arrange that—

$$\omega LI = \frac{I}{\omega C}.$$

By arranging this equation in another form we get—

$$\omega L = \frac{I}{\omega C},$$

$$\text{or, } \omega^2 = \frac{I}{LC},$$

$$\text{or, } \omega = 2\pi f = \frac{1}{\sqrt{LC}} \tag{7}$$

$$\text{or, } f = \frac{1}{2\pi\sqrt{LC}} \text{ where } \begin{cases} L = \text{henries,} \\ C = \text{farads.} \end{cases} \tag{8}$$

This equation is widely used in wireless telegraphy.

If we arrange to satisfy it, either by altering the applied frequency so that it is equal to $\frac{1}{2\pi\sqrt{LC}}$, or by altering the value of the inductance or the capacity of the circuit so that the expression $\frac{1}{2\pi\sqrt{LC}}$ is equal to the applied frequency f, then the counter E.M.F.'s of inductance and capacity "cancel out," and none of the applied voltage is required to make good their difference.

That is to say, since $\omega L = \frac{1}{\omega C}$, the expression

$$I = \frac{V}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

becomes $I = \frac{V}{\sqrt{R^2}} = \frac{V}{R}$, and, so far as the applied voltage is concerned, the **circuit behaves as if it comprised resistance only.**

The current neither lags nor leads, but is in phase with the applied voltage, because $\tan \phi = \frac{X_L - X_C}{R} = \frac{0}{R} = 0$, and therefore $\phi = 0°$.

**234.** The condition described above is known as "**Electrical Resonance,**" and the frequency that satisfies the equation is known as the "**Resonant Frequency.**"

It is also known as the "**Natural Frequency**" of the circuit, for it is the frequency at which the circuit will naturally oscillate if set in electrical vibration.

Since the natural frequency of the circuit depends upon the LC value of this circuit, this product LC is often called the "Oscillation Constant" or "Resonance Constant" of the circuit (*see* para. **300**).

**235. Acceptor Circuit.**—A circuit comprising inductance and capacity in series, which is in resonance with the frequency applied to it, is said to be an "**Acceptor Circuit**" for that frequency.

All circuits of the same LC value are obviously acceptor circuits for the same frequency.

For example, if in a certain circuit you double the inductance and halve the capacity the counter E.M.F.s of each will both be doubled, and they will still "cancel out."

**236.** As in W/T we are generally working in units of mics and jars, and not of henries and farads, it is convenient to turn the above formula into terms of mics and jars, as follows :—

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \begin{cases} \text{L in henries,} \\ \text{C in farads.} \end{cases}$$

$$= 2\pi \frac{1}{\sqrt{\frac{L}{10^6} \times \frac{C}{9 \times 10^8}}} = \frac{\sqrt{9 \times 10^{14}}}{2\pi\sqrt{LC}} = \frac{3 \times 10^7}{2\pi\sqrt{LC}} \qquad (9)$$

$$\text{where } \begin{cases} L = \text{mics}, \\ C = \text{jars}. \end{cases}$$

$$\text{or } \omega = \frac{3 \times 10^7}{\sqrt{LC}}.$$

If an approximate value of 6·28 be taken for $2\pi$, then the above formula becomes—

$$f = \frac{4{\cdot}774 \times 10^6}{\sqrt{LC}} = \frac{4{\cdot}8 \times 10^6 *}{\sqrt{LC}} \text{ approximately} \qquad (10)$$

$$\begin{cases} f \text{ in cycles per second,} \\ L \text{ in mics,} \\ C \text{ in jars.} \end{cases}$$

**Example 32.**

(i) Find the correct resonant frequency for the circuit given in Example 31.

(ii) If an alternating voltage of 50 volts at this frequency be applied to the circuit, find the answer to (*a*) (*b*) (*c*) and (*d*) as before.

$$\text{(i) } f = \frac{3 \times 10^7}{2\pi\sqrt{LC}} = \frac{3 \times 10^7}{2\pi\sqrt{900}} = \frac{3 \times 10^7}{2\pi \times 30} = \frac{10^6}{2\pi} =$$

159,200 cycles per second.

$$\text{(ii) (a) } \omega = \frac{3 \times 10^7}{\sqrt{LC}} = \frac{3 \times 10^7}{\sqrt{900}} = \frac{3 \times 10^7}{30} = 10^6.$$

$$\begin{cases} X_L = \omega L = 10^6 \times \frac{900}{10^6} = 900 \text{ ohms.} \\ X_C = \frac{1}{\omega C} = \frac{1}{10^6} \times \frac{9 \times 10^8}{1} = 900 \text{ ohms.} \end{cases}$$

$$X_L - X_C = 0. \quad I = \frac{V}{R} = \frac{50}{10} \times 5 \text{ ampères.}$$

$$\text{(b) } \tan\phi = \frac{X_L - X_C}{R} = \frac{0}{10} = 0, \text{ hence } \phi = 0°.$$

$$\text{(c) } \omega LI = X_L I = 900 \times 5 = 4{,}500 \text{ volts.}$$

$$\text{(d) } \frac{I}{\omega C} = X_C I = 900 \times 5 = 4{,}500 \text{ volts.}$$

Notice particularly that the voltages across the inductance and capacity are very much greater than the applied voltage.

This occurs when the reactance of the inductance or of the capacity is great compared with the resistance of the circuit; advantage is continually taken of this fact in W/T circuits.

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* It must be remembered that the expression $f = \frac{4{\cdot}8 \times 10^6}{\sqrt{LC}}$ is only a very rough approximation, and should not be used if an accurate answer is required.

**Example 33.**

Find how much inductance is required in series with a condenser of 2 jars capacity to make the circuit an acceptor for a frequency of 500,000 per second.

$$f = \frac{4\cdot 8 \times 10^6}{\sqrt{LC}},$$

$$500{,}000 = \frac{4\cdot 8 \times 10^6}{\sqrt{2L}},$$

$$\sqrt{2L} = \frac{4\cdot 8 \times 10^6}{5 \times 10^5} = \frac{48}{5},$$

$$L = \left(\frac{48}{5}\right)^2 \times \frac{1}{2} = 46 \text{ mics.}$$

**237.—Resonance in Daily Life.**—The fact that very big voltages build up across the inductance and capacity of a circuit if, *and only if*, it is tuned to be in resonance, or nearly so, with the frequency of the current applied to it, is continually made use of in W/T. In fact W/T would be quite impossible, if the phenomenon of resonance did not exist.

Resonance may be defined as the transference of energy from one system to another in a series of periodic impulses or waves timed exactly to coincide with the natural rate of vibration of the second system.

Numerous cases of this phenomenon occur in daily life. Watch, for instance, one child swinging another in a swing; how carefully it gives each little push exactly as the swing has reached its limit and begins to go forward, and how the energy of each push is added to that of the moving swing so that very soon it would knock over a man who stepped in its way.

Walk across a room carrying a cup of tea, and note how quickly it slops over if your step is in time with its natural swing, and how by walking with short irregular steps it is much more easy to avoid spilling it.

A good demonstration of resonance can also be given with a sponge in a bath. Just swing it to-and-fro in time with the wave it produces, and in a very few moments you will find the water is also swinging from end to end of the bath with rapidly increasing energy, and here also you will find that exact timing of the impulses is the sole condition of success.

**238.** Notice that if the applied frequency is increased or decreased above or below the resonant frequency, then $\omega L$ is no longer equal to $\frac{1}{\omega C}$, and the current flowing is reduced if the applied voltage remains the same.

If the frequency is **increased**, $\omega L$ becomes greater and $\frac{1}{\omega C}$ becomes less, and the tendency to lag will be greater than the tendency to lead; the resultant current is therefore one that **lags** behind the applied voltage.

Conversely, if the frequency is **decreased** below the resonant one, $\frac{1}{\omega C}$ becomes greater than $\omega L$, and the resultant current will **lead** the applied voltage.

**239. The amount by which the current is cut down depends on the proportion of inductance to capacity.** Taking a circuit of a constant LC value, energised by a voltage whose frequency is not the correct one for resonance, the current flowing will be equal to—

$$\frac{V}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}.$$

The greater the value of the inductance, and the less the value of the capacity used to make up this LC value, the greater will both the expressions $\omega L$ and $\frac{1}{\omega C}$ become, the greater will be their difference, and the less the value of the resultant current.

This point will be made clear by an example.

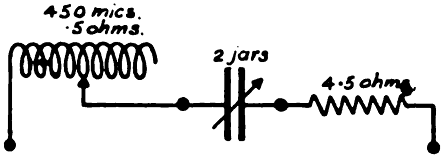


FIG. 125.

**Example 33.**

(*a*) In the above circuit consisting of an inductance of 450 mics. in series with a condenser of 2 jars, the inductance has a resistance of ·5 ohms to every 450 mics, and there is an additional resistance in the circuit of 4·5 ohms. Find what voltage will be required to make a current of 1 ampère flow (i) at the resonant frequency (ii) with an applied frequency which is ¾ths of the resonant one.

$$\text{(i) } \omega = \frac{3 \times 10^7}{\sqrt{LC}} = \frac{3 \times 10^7}{\sqrt{900}} = 10^6.$$

$$\left.\begin{aligned} X_L &= \omega L = 10^6 \times \frac{450}{10^6} = 450. \\ X_C &= \frac{1}{\omega C} = \frac{1}{10^6} \times \frac{9 \times 10^8}{2} = 450. \end{aligned}\right\} X_L - X_C = 0.$$

$$Z = R = 4{\cdot}5 + {\cdot}5 = 5 \text{ ohms.}$$

$$V = IR = 1 \times 5 = 5 \text{ volts.}$$

**Conversely**, for each volt applied a current of $\frac{1}{5}$ ampère will flow.

(ii) $\omega' = \frac{3}{4} \times 10^6$.

$$\left.\begin{aligned} X_L &= \omega' L = \frac{3 \times 10^6}{4} \times \frac{450}{10^6} = \frac{1350}{4} = 337\cdot5 \\ X_C &= \frac{1}{\omega' C} = \frac{4}{3 \times 10^6} \times \frac{9 \times 10^8}{2} = 600 \end{aligned}\right\} \begin{array}{c} X_C - X_L = \\ 600 - \\ 337\cdot5 = \\ 262\cdot5 \text{ ohms.} \end{array}$$

$$Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{5^2 + 262\cdot5^2} = 263.$$

$$V = IZ = 1 \times 263 = 263 \text{ volts.}$$

Conversely, for each volt applied a current of $\frac{1}{263}$ amp. will flow.

That is to say the current at the resonant frequency is to the current at the non-resonant frequency as

$$\frac{1}{5} : \frac{1}{263} \text{ or as } 52 : 1 \text{ approximately.}$$

The current at non-resonant frequency can, however, be still more cut down.

(*b*) Find the currents flowing for the two applied frequencies if the inductance is increased to 4,500 mics, and the capacity is reduced to ·2 jar; *i.e.*, if the ratio L/C is increased from 225 : 1 to 22,500 : 1.

(*a*) as before, $\omega = 10^6$

$$\left.\begin{aligned} \omega L &= 10^6 \times \frac{4500}{10^6} = 4500 \\ \frac{1}{\omega C} &= \frac{1}{10^6} \times \frac{9 \times 10^8}{\cdot2} = 4500 \end{aligned}\right\} X_L - X_C = 0.$$

The resistance will now be $(\cdot5 \times 10) + 4\cdot5 = 9\cdot5$ ohms.
Required voltage $= IR = 1 \times 9\cdot5 = 9\cdot5$ volts.

Conversely, for each volt applied a current of $\frac{1}{9\cdot5}$ ampère will flow.

(*b*) $\omega' = \frac{3}{4} \times 10^6$

$$\left.\begin{aligned} X_L &= \omega' L = \frac{3 \times 10^6}{4} \times \frac{4500}{10^6} = 3375 \\ X_C &= \frac{1}{\omega' C} = \frac{4}{3 \times 10^6} \times \frac{9 \times 10^8}{\cdot2} = 6000 \end{aligned}\right\} \begin{array}{c} X_C - X_L = \\ 2625 \end{array}$$

$$Z = \sqrt{9\cdot5^2 + 2625^2} = 2625.$$

$$V = I \times Z = 1 \times 2625 = 2625 \text{ volts.}$$

Conversely, for each volt applied a current of $\frac{1}{2625}$ ampère will flow.

Hence the current at the resonant frequency is to the current at the interfering frequency as :—

$$\frac{1}{9\cdot5} : \frac{1}{2625} \text{ or as } 273 : 1\text{, approximately.}$$

From this we may deduce that the greater the inductance and the smaller the capacity (or "**the greater the ratio $\frac{L}{C}$**") the less current flows at any "out-of-resonance" frequency.

Note.—Circuits where the ratio L/C is big are spoken of as being "stiff" circuits.

**240.** Let us now take an example of resonance with a low frequency circuit.

**Example 34.**

(*a*) Find how much inductance is required for resonance in series with a condenser of 160 jars, if the applied voltage is 400 volts at a frequency of 350 cycles.

(*b*) Find the voltage across the condenser if the resistance of the circuit is 20 ohms.

(*a*) $f = \frac{4\cdot8 \times 10^6}{\sqrt{LC}}$. Therefore $\sqrt{160L} = \frac{4\cdot8 \times 10^6}{350}$

$$L = \left(\frac{4\cdot8 \times 10^6}{350}\right)^2 \times \frac{1}{160}$$
$$= 1{,}175{,}000 \text{ mics.}$$
$$= 1\cdot175 \text{ henries.}$$

(*b*) $\omega = 2\pi \times 350 = 2198 = 2200$ approx.

$$X_C = \frac{1}{\omega C} = \frac{9 \times 10^8}{2200 \times 160} = \frac{9 \times 10^5}{352} = 2560 \text{ ohms.}$$

As the circuit is in resonance, $I = \frac{V}{R} = \frac{400}{20} = 20$ amps.

$$X_C I = 2560 \times 20 = 51{,}200 \text{ volts.}$$

**241.** The voltage across the inductance or condenser in a resonant circuit where the current is known may be found more conveniently in the following manner, without working out the frequency :—

The voltage across the inductance $= \omega LI$, which is equal to $\frac{I}{\omega C}$, the voltage across the condenser.

Hence $E_L = E_C = \omega LI$; but $\omega = \frac{1}{\sqrt{LC}}$,

$$\text{therefore } E_L = \frac{LI}{\sqrt{LC}} = I\sqrt{\frac{L}{C}} \text{ where } \begin{cases} L = \text{henries,} \\ C = \text{farads.} \end{cases} \qquad (11)$$

Bringing henries to mics and farads to jars, we have—

$$E_L = E_C = I\sqrt{\frac{L}{10^6} \times \frac{9 \times 10^8}{C}} = I\sqrt{\frac{900L}{C}}$$
$$= 30\,I\sqrt{\frac{L}{C}} \text{ where } \begin{cases} L = \text{mics,} \\ C = \text{jars.} \end{cases} \qquad (12)$$

This formula is useful in cases where the inductance and capacity of a circuit are both "concentrated," and not composed of several inductances and capacities in series or parallel.

**Example 35.**

In a circuit consisting of an inductance of 700 mics, a condenser of 1 jar, and a resistance of 30 ohms in series, find the voltage (*a*) across the condenser (*b*) across the supply terminals, for a current of 10 R.M.S. ampères through the circuit.

(*a*) the resonant voltage across the condenser

$$E = 30\,I\sqrt{\frac{L}{C}} = 30 \times 10\sqrt{\frac{700}{1}} = 300 \times 26{\cdot}5 =$$

$$7950 \text{ R.M.S. volts.}$$

The maximum value of this voltage will be—

$$7950 \times \sqrt{2} = 7950 \times 1{\cdot}414 = 11{,}240 \text{ volts.}$$

(*b*) the voltage required across the circuit to force the current of 10 R.M.S. ampères through the resistance of the circuit at resonant frequency will be—

$V = I\,R = 10 \times 30 = 300$ R.M.S. volts.

$V_m$ = maximum voltage required $= 300 \times \sqrt{2} = 300 \times 1{\cdot}414 = 424$ volts.

**242.** To sum up the characteristics of an acceptor circuit :—

(*a*) **For the resonant frequency** the current flowing depends solely on the resistance of the circuit, since the counter E.M.F.'s of inductance and capacity neutralise one another exactly.

(*b*) For any other **non-resonant frequency,** those counter E.M.F.'S do not neutralise one another; some of the applied voltage is required to make good the difference

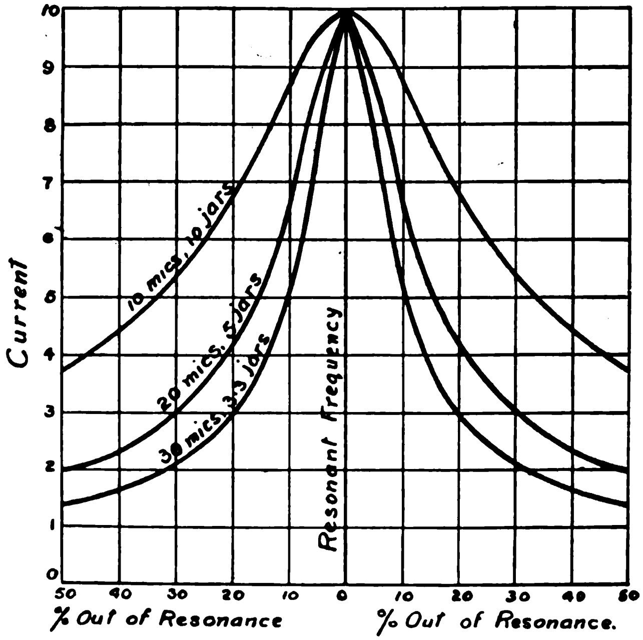


FIG. 126.

between them, and the current flowing through the circuit is cut down if the applied voltage remains the same.

(*c*) For any given LC value, the greater the ratio of inductance to capacity the greater the reduction of current at the non-resonant frequency.

(*d*) If the applied voltage is higher in frequency than the resonant one, the current will lag, and *vice versâ*.

These facts are illustrated in Fig. 126, which shows the current flowing through a circuit tuned to 100 LC—made up of 10 mics and 10 jars, 20 mics and 5 jars, or 30 mics and 3·33 jars, in series—the resistance of the circuit being 10 ohms and the voltage applied being 100 volts; current strength is plotted against applied frequency, *i.e.*, the resonant frequency which gives the maximum current in each case, and frequencies 10 per cent., 20 per cent., 30 per cent., &c., different from the resonant frequency.

These curves bring out clearly how the reduction of current at non-resonant frequencies is increased by an increase in the ratio of inductance to capacity.

**243. Acceptor Circuits in Series.**—It is often desirable to join two or more acceptor circuits in series.

The tuning of the whole circuit is not altered, but the ratio L/C is increased.

Suppose two circuits, $L_1C_1$ and $L_2C_2$ are joined in series, and that each is tuned to the same LC value; *i.e.*, that $L_1C_1 = L_2C_2$.

$$\text{If } L_1C_1 = L_2C_2$$

$$\text{then } L_1 = \frac{L_2C_2}{C_1} \text{ and } L_2 = \frac{L_1C_1}{C_2}.$$

$$\text{Hence } L_1 + L_2 = \frac{L_2C_2}{C_1} + \frac{L_1C_1}{C_2}$$

$$= L_1C_1\left(\frac{1}{C_1} + \frac{1}{C_2}\right) \text{ since } L_1C_1 = L_2C_2$$

$$= L_1C_1\left(\frac{C_1 + C_2}{C_1 \times C_2}\right) \quad . \quad . \quad . \quad . \quad . \quad (a)$$

The LC value of the two inductances and the two capacities in series will be :—

$$(L_1 + L_2)\left(\frac{C_1 \times C_2}{C_1 + C_2}\right)$$

$$\text{which equals } L_1C_1\left(\frac{C_1 + C_2}{C_1 \times C_2}\right)\left(\frac{C_1 \times C_2}{C_1 + C_2}\right) \text{ from } (a)$$

$$= L_1C_1 = L_2C_2.$$

Hence the LC value of the whole circuit is equal to that of either of the two combinations.

This is further explained by an example :—

**Example 36.**

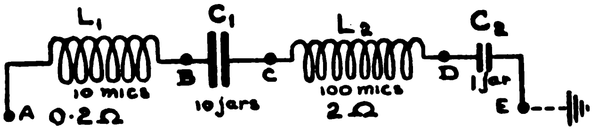


Fig. 127.

The circuits A to C and C to E are each tuned separately to 100 mic-jars.

$$\text{The total inductance} = 10 + 100 = 110 \text{ mics.}$$

$$\text{The total capacity} = \frac{10 \times 1}{10 + 1} = \frac{10}{11} \text{ jars.}$$

The LC value of the circuit A to E is therefore

$$110 \times \frac{10}{11} = 100 \text{ mic-jars,}$$

but notice that the ratio L/C is now $110 : \frac{10}{11}$, or 121 : 1, instead of 1 : 1 as in the case of the circuit A to C, or 100 : 1 as in the case of the circuit C to E.

Hence, if two or more acceptor circuits are joined in series, the tuning of the whole circuit is not altered, but the ratio L/C is increased.

**244.** It will be instructive to note the distribution of voltage in the above circuit.

Assume the resistance of $L_1$ is ·2 ohms, that of $L_2$ is 2 ohms, and that a current of 1 ampère is flowing at the resonant frequency. Find the P.D. across the various portions of the circuit.

As the circuit is in resonance, and as the resistance is small compared to the reactance, we may use formula (12).

$$\text{Voltage A to B} = \text{voltage B to C} = 30\ I\sqrt{\frac{L}{C}} =$$

$$30 \times 1 \times \sqrt{\frac{10}{10}} = 30 \text{ volts.}$$

Similarly voltage C to D = voltage D to E = $30 \times 1 \times \sqrt{\frac{100}{1}} = 300$ volts.

The voltage required to drive the current through the resistance of the acceptor circuit A to C = I × R = 1 × ·2 = ·2 volts.

Similarly the voltage across the acceptor circuit C to E

$$= I \times R = 1 \times 2 = 2 \text{ volts.}$$

The voltage required to drive the current through the resistance of the combined circuits = ·2 + 2 = 2·2 volts.

The voltages across the various portions of the circuit are therefore as follows :—

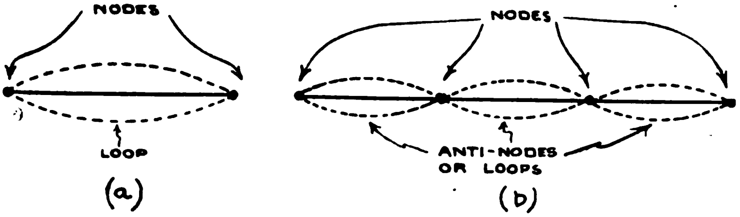
A — B : 30 volts.
B — C : 30 volts.
A — C : ·2 volts.
C — D : 300 volts.
D — E : 300 volts.
C — E : 2 volts.
A — E : 2·2 volts.

The power required to maintain the current $= I^2R = 1^2 \times 2\cdot2 =$ $2\cdot2$ watts.

This example will be found to be useful when dealing with receiving circuits later.

**245. Potential Nodes and Loops.**—In W/T one meets with great variations of potential between various portions of a circuit, and the question is important when considering the value of the insulation that must be provided.

The portions of a circuit where the potential does not vary much are often referred to as "nodes of potential," and the points undergoing large potential changes are termed "anti-nodes" or "loops" of potential.



*A Vibrating Violin String.*

FIG. 128.

Take a taut violin string and pluck it; it will vibrate as shown by the dotted lines, Fig. 128 (*a*). The two ends which are secured cannot move; these two points are called "nodes" of vibration. The centre of the string will have a maximum of movement; this point is called a "loop" or "anti-node" of vibration.

Now press the string lightly at a point one-third of its length from one end, Fig. 128 (*b*). This point and the two ends are held fixed. The remaining two-thirds will automatically divide itself into two equal vibrating portions, with the mid-point stationary. The string will vibrate, and emit a note which is three times the frequency of the fundamental note as given by the string in Fig. 128 (*a*).

This note is called **the third harmonic.**

As can be seen from the figure, we have in this second case four nodes and three anti-nodes of vibration.

Various interesting experiments of this nature may be tried by applying regularly timed jerks to a taut signal halyard or stay.

Similarly, with the wireless circuit we have just been discussing. Suppose we earth the point E. Then the point D will be oscillating at 300 volts above and below earth potential.

The potential of the point C will only vary 2 volts either way.

The point B will vary 30 volts, and A will vary 0·2 volts with respect to C.

Thus A, C and E may be spoken of as nodes of potential, and B and D as anti-nodes, or loops of potential.

D must have insulation from earth adequate to stand 300 volts, C to stand 2 volts, B to stand 30 volts, and A to stand 2·2 volts.

**246. Inductance and Capacity in Parallel.**—General Case, neglecting resistance.

(It must be clearly understood that in this and succeeding paragraphs up to and including paragraph 251, the existence of resistance is entirely neglected and that the value obtained for I (= zero) in paragraph **247** is based on this hypothesis.)

If an alternating voltage of V volts at a frequency of f cycles per second be applied to a circuit, as shown in Fig. 129 (*a*), con-

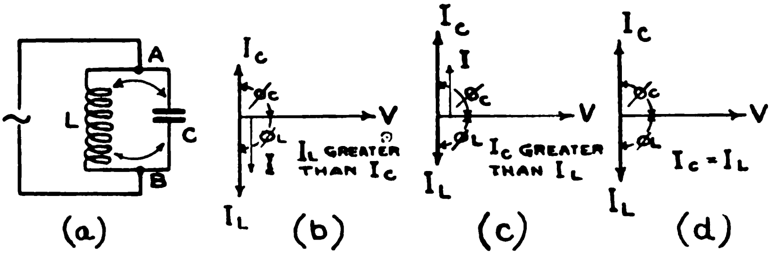


Fig. 129.

sisting of a condenser and inductance in parallel, then the current flowing through the circuit can be arrived at in the following manner :—

(*a*) a current $I_L$ will flow through the inductance L such that $I_L = \frac{V}{\omega L}$, and is **lagging** behind the applied voltage V by an angle $\phi_L$ of 90°;

(*b*) a current $I_C$ will flow through the condenser C such that $I_C = \omega CV$, and is **leading** on the applied voltage V by an angle $\phi_C$ of 90°.

The A.C. source must supply both these two, but as they are exactly opposite in phase the current (I) which will actually flow from the A.C. source will be their **difference,** as indicated in Fig. 129 (*b*) and (*c*).

$$\text{Thus } I = I_C - I_L = \omega CV - \frac{V}{\omega L} = V\left(\omega C - \frac{1}{\omega L}\right) \qquad \textbf{(13)}$$

Just as in the series case the A.C. source had to supply the difference between the **voltages across** the inductance and condenser (para. **232**), so here it has to supply the difference between the **currents through** the inductance and condenser.

**247. Resonant Case, neglecting Resistance.**—Let a voltage be applied to the circuit such that $\frac{1}{\omega L} = \omega CV$ : *i.e.*, that $\frac{V}{\omega L} = \omega CV$.

Then $I_L = I_C$ (Fig. 129 (*d*) ).

These two are 180° out of phase, and **therefore no current can flow from the A.C. source.**

That is, $I = V\left(\omega C - \frac{1}{\omega L}\right) = V \times 0 = 0$.

Such a frequency of supply is termed the Resonant Frequency for the circuit, and is such that

$$f = \frac{1}{2\pi\sqrt{LC}}.$$

This statement means that if a voltage at the resonant frequency is applied to the circuit, no current will be able to flow through the circuit from the A.C. supply, although there will be a large "circulating" current equal to $I_L$ or $I_C$ flowing round the circuit.

**248.** This result at first sight appears impossible, as if the circuit had an infinitely great impedance.

What happens is that a circulation, or oscillation, is set up in the circuit of a current which justs keeps time with the pulsations of the voltage in the supply mains.

This current oscillating to and fro, as indicated in Fig. 129 (*a*), gives rise at the terminals A, B to an alternating E.M.F. which absolutely coincides in point of time with the voltage of supply.

Moreover, it coincides in magnitude, so that no current at all from the supply mains can enter this self-contained circuit.

All the above is based on the assumption that the circuit contains absolutely no resistance. If it does, as must be the case to a greater or less extent in practice, a certain current will flow through the circuit at the resonant frequency, as is shown in para. **253.**

A resonant circuit composed of inductance and capacity in **parallel is termed a "Rejector" circuit,** being exactly opposite in its effects to an Acceptor circuit.

**249.** In the case of the resonant series circuit, the counter E.M.F.'s across the inductance and condenser neutralised one another, whereas in the case of the resonant parallel circuit, we have mutually neutralising currents, and whereas in the series case the circuit offers a minimum impedance to current at the resonant frequency, in the parallel case it offers a maximum impedance.

The two circuits are thus diametrically opposite in their effects.

**250. Circulating Current.**—Although no current can flow **through** the circuit from the A.C. source, a current does alternate round the circuit, viz :—a current $I_R$ (rejector current) which equals $I_L$ or $I_C$.

This current can be readily calculated as follows :—

$$\left.\begin{aligned} I_R = I_L = \frac{V}{\omega L}. \qquad \omega &= \frac{1}{\sqrt{LC}} \\ \text{Therefore } I_R = V\,\frac{\sqrt{LC}}{L} &= V\sqrt{\frac{C}{L}} \end{aligned}\right\}\ \text{C \& L being in units of farads and henries.} \qquad (14)$$

Reducing this expression to terms of jars and mics, we have

$$I_R = V\sqrt{\frac{C \times 10^6}{9 \times 10^8 \times L}} = \frac{V}{30}\sqrt{\frac{C}{L}}. \qquad (15)$$

To enable these circulating currents to flow, the supply source, when the voltage is **first** applied, must furnish a certain amount of energy, viz.: $\frac{1}{2}LI^2$ or $\frac{1}{2}CV^2$ joules, which, assuming no resistance, is sufficient to maintain the circulating current indefinitely.

**251. Non-resonant Case, neglecting Resistance.**—Let us assume a different frequency of supply, which may be greater or less than the resonant one.

Let $\omega_1$ be equal to $2\pi f_1$, where $f_1$ is a frequency higher than f, the resonant frequency.

The current from the A.C. source

$$= I = V\left(\omega_1 C - \frac{1}{\omega_1 L}\right) \text{ ampères (from (13)}$$

$$\frac{1}{\omega_1 L} \text{ will be less than } \frac{1}{\omega L} : \ \omega_1 C \text{ will be greater than } \omega C.$$

Thus $I_C$ will be greater than $I_L$, and a certain current will flow from the A.C. source, leading the applied voltage, as in Fig. 129 (*c*).

Similarly a frequency lower than f will result in a preponderance of current through the inductance, and the current from the A.C. source will be one lagging behind the applied voltage, as in Fig. 129 (*b*).

Further, for a given LC value and a given non-resonant frequency, the bigger we make the ratio of C to L the greater the expression $\left(\omega_1 C - \frac{1}{\omega_1 L}\right)$ becomes, and so the greater the current (I) from the A.C. source.

In other words, the greater the ratio C/L, the **less** is the impedance of the circuit to current at non-resonant frequencies.

**Example 37.**

218. If an alternating voltage of 1 volt be applied to a circuit consisting of an inductance of 4 mics in parallel with a condenser of 25 jars (*a*) at the resonant frequency, (*b*) at a frequency of 500,000 cycles, find the circulating current in the first case, and the current from the supply in the second case.

(*a*) Circulating current—

$$= \frac{V}{30}\sqrt{\frac{C}{L}} = \frac{1}{30}\sqrt{\frac{25}{4}}$$

$$= \frac{1}{30} \times \frac{5}{2} = \frac{1}{12} \text{ amp.} = \frac{1000}{12} = 83 \cdot 3 \text{ milliamps.}$$

(*b*) $\omega = 2\pi \times 5 \times 10^5 = \pi \times 10^6$ radians per sec.

$$I_C = \omega CV = \frac{3 \cdot 14 \times 10^6 \times 25 \times 1000}{9 \times 10^8} \text{ milliamps.}$$

$$= 87 \cdot 2 \text{ mA.}$$

$$I_L = \frac{V}{\omega L} = \frac{1}{3 \cdot 14 \times 10^6} \times \frac{10^6 \times 1000}{4} = \frac{1000}{12 \cdot 56} = 79 \cdot 6 \text{ mA.}$$

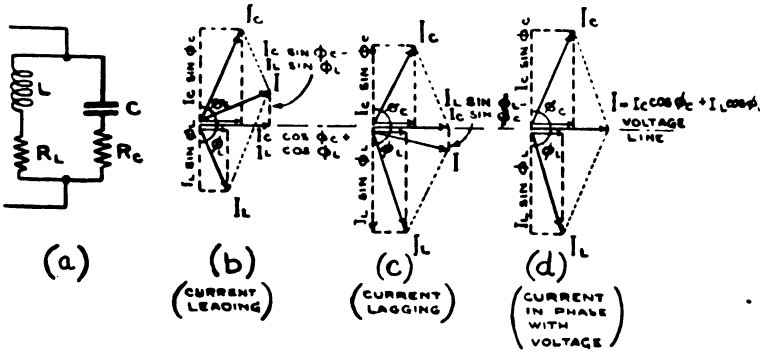
$$I_C - I_L = 87 \cdot 2 - 79 \cdot 6 = 7 \cdot 6 \text{ milliamps.}$$

The supply current is therefore one of 7·6 milliampères, leading by 90°, since the condenser current is greater than the inductance current.

**252. General Case, including Resistance.**—So far we have been dealing with a circuit containing no resistance whatever.

In practice, such a state of affairs is not possible, although in an efficient circuit the resistances are small.

Let us take a case where there is resistance in each branch of the circuit.


L
C
$R_L$
$R_C$
$I_C$
$I_C \sin \phi_C$
$I_L \sin \phi_L$
$I_C \sin \phi_C - I_L \sin \phi_L$
I
$\phi_C$
$\phi_L$
$I_C \cos \phi_C + I_L \cos \phi_L$
$I_L$
$I_L \sin \phi_L - I_C \sin \phi_C$
$I = I_C \cos \phi_C + I_L \cos \phi_L$
VOLTAGE LINE

(a) (b) (CURRENT LEADING) (c) (CURRENT LAGGING) (d) (CURRENT IN PHASE WITH VOLTAGE)

FIG. 130.

Owing to the presence of resistance, the current through the inductance branch will not now be equal to $\frac{V}{\omega L}$ but to $\frac{V}{\sqrt{R_L^2 + (\omega L)^2}}$; it will not be lagging by 90°, but by some less angle $\phi_L$.

Similarly, the current through the condenser branch will be equal to—

$$\frac{V}{\sqrt{R_C^2 + \left(\frac{1}{\omega C}\right)^2}},$$

and will be leading by some angle $\phi_C$ which will be less than 90°.

The current I from the supply source must, as before, be the resultant of $I_L$ and $I_C$, but it is not so easily determined.

Let us split up $I_L$ and $I_C$ into components in phase with the applied voltage, and components 90° out of phase with it.

$I_L$ may be split up into—

$I_L \sin \phi_L$, lagging 90° behind the applied voltage, and $I_L \cos \phi_L$, in phase with the applied voltage (*see* Appendix A, page 503).

Similarly, the current $I_C$ may be split up into $I_C \sin \phi_C$, leading 90° on the applied voltage, and $I_C \cos \phi_C$ in phase with it.

The supply current now has two things to do—

(*a*) to supply **the difference** between $I_L \sin \phi_L$ and $I_C \sin \phi_C$; *i.e.*, $I_L \sin \phi_L - I_C \sin \phi_C$

and

(*b*) to supply both components in phase with the applied voltage, *i.e.*, $I_L \cos \phi_L + I_C \cos \phi_C$. (*See* Fig. 130 (*b*) and (*c*) ).

**253. Resonant Case, including Resistance.**—For our given $R_L$ and $R_C$, we shall get minimum current flowing from the supply (and therefore maximum impedance) when the vertical components of $I_L$ and $I_C$ are equal; *i.e.*, when $I_C \sin \phi_C = I_L \sin \phi_L$, for then the current from the supply has only to make good the horizontal components of $I_L$ and $I_C$: viz., $I_C \cos \phi_C + I_L \cos \phi_L$. In this condition the supply current and volts are in phase (*vide* Fig. 130 (*d*) ).

**254.** A method of arriving at an approximation of the required current from the supply in the resonant case, is as follows :—

The watts expended in any resistance $= I^2R$.

Now in the circuit shown in Fig. 130 (*a*) the circulating current is flowing through the resistances $R_L + R_C = R$ : also, the circulating current $I_R = V\sqrt{\frac{C}{L}}$, as a close approximation.

Hence the watts expended in the circuit :—

$$= I^2_R\, R = V^2 \frac{C}{L} \times R = V^2 \frac{RC}{L}.$$

The alternating supply will have to make good this expenditure of energy in order to maintain the circulating current.

If V = the supply voltage, and I the supply current required, then—

$$VI \text{ must be equal to } V^2 \frac{RC}{L},$$

That is, I (the supply current) $= V\dfrac{RC}{L}$ ampères

$$\text{where}\begin{cases} C = \text{farads.} \\ L = \text{henries.}\end{cases}$$

$$= VR\frac{C}{9\times10^8}\times\frac{10^6}{L} = V\frac{RC}{900L}\ \text{where}\begin{cases} C = \text{jars.} \\ L = \text{mics.}\end{cases} \qquad \textbf{(16)}$$

**Example 38.**

**If an alternating voltage of 10 volts be applied to a circuit consisting of 100 jars in parallel with an inductance of 4 mics at the correct resonant frequency, find (*a*) the supply current required (*b*) the circulating current, if the resistance of the circuit is equal to 0·1 ohm.**

(*a*) Supply current $= V\dfrac{RC}{900L}$ from (16)

$$= 10\times\frac{0\cdot1\times100}{900\times4} = \frac{1}{36} = \cdot028 \text{ ampères.}$$

(*b*) Circulating current $= I_R = \dfrac{V}{30}\sqrt{\dfrac{C}{L}}$ from (15)

$$= \frac{10}{30}\sqrt{\frac{100}{4}} = \frac{5}{3} = 1\cdot67 \text{ ampères.}$$

**255. Non-resonant Case, including Resistance.**—When the vertical components of $I_L$ and $I_C$ are not equal, the supply source will have to make good the two horizontal components **and also** the difference between the vertical components.

The current from the supply will be the resultant of $(I_L \sin\phi_L - I_C \sin\phi_C)$ and $(I_L\cos\phi_L + I_C\cos\phi_C)$, as indicated in Fig. 130 (*b*) and (*c*) ).

The supply current must, therefore, be greater than before assuming the same inductance, capacity and applied voltage, and will lag behind or lead the applied voltage accordingly as the applied frequency is less or greater than the resonant one.

**256. The power** required from the supply will be the supply voltage multiplied by the supply current. Thus, in the resonant case the power required will be $V\times I_L\cos\phi_L + V\times I_C\cos\phi_C$.

**257.** To sum up the properties of a Rejector circuit :—

(*a*) **Resonant Frequency.**—If the circuit has no resistance losses at all, it allows no current to flow through it from the source of supply, although a large circulating current is set up in the circuit.

If it has any resistance losses, a supply current can flow through it, which is greater :—

(i) the greater the resistance losses,

(ii) the greater the ratio C/L.

(*b*) **Non-resonant Frequencies.**—If any non-resonant frequency is applied, the current from the supply must increase and will be out of phase with the applied voltage.

The current flowing through is greater—

(i) the greater the difference of this non-resonant frequency from the resonant one, and

(ii) the greater the ratio C/L.

These facts are illustrated in Fig. 131, which shows the current flowing through a circuit tuned to 100 LC—made up of 10 mics and 10 jars, 5 mics and 20 jars, or 3·33 mics and 30 jars, in parallel—with one ohm resistance in each side of the circuit, and 100 volts applied; current strength is plotted against applied frequency, as in Fig. 126.

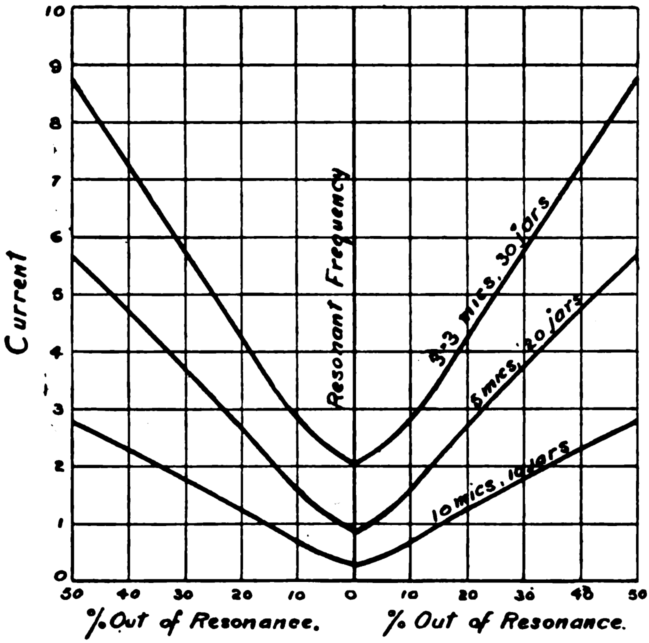


FIG. 131.

These curves show that the supply current is a minimum at the resonant frequency, while for non-resonant frequencies it is greater, the greater the proportion of capacity to inductance.

**258. Comparison between Acceptor and Rejector Circuits.**—The essential differences between acceptor and rejector circuits are of great importance.

The two circuits are exactly opposite in their effects.

The acceptor circuit is an easy path for currents at the resonant frequency, and a difficult one for all others, whereas the rejector is a difficult path for current at the resonant frequency and an easy path for all others.

The formula for the resonant acceptor circuit is $I = \frac{V}{R}$, so that the less the resistance, the greater is the current.

The formula for the resonant rejector circuit is $I = V \times \frac{RC}{L}$, so that the less the resistance, the less the current, and also the proportion of capacity to inductance affects the result, which it does not do in the former case.

It should be particularly remembered that a parallel resonant circuit will become a less and less efficient rejector circuit, the greater its resistance, as it will allow a large current to flow from the source both at resonant and non-resonant frequencies.

**259. Power in an Alternating Current Circuit.**—In any **direct** current circuit, the expenditure of power is easily obtainable in any one of three ways.

(*a*) If the current and applied voltage are known, then the power expenditure (in watts) is equal to $V \times I$.

(*b*) If the resistance of the circuit, and the current flowing through the resistance, are known, then the power expenditure

$$= VI = IR \times I = I^2 R.$$

(*c*) If the resistance of the circuit, and the applied voltage, are known, then the power expenditure

$$= VI = V \times \frac{V}{R} = \frac{V^2}{R}.$$

**260.** This is not the case in an **alternating** current circuit.

Fig. 132 (*b*) illustrates a simple circuit where an A.C. source is forcing current through an inductance L and a resistance R. An ammeter (A) is reading the R.M.S. value of the current flowing, and a voltmeter (V) reads the R.M.S. value of the applied voltage.

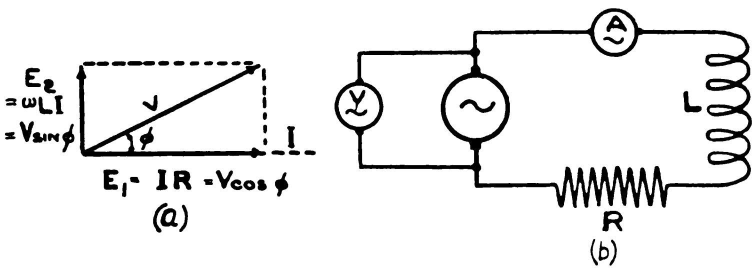


Fig. 132.

Then we know that the current will be lagging behind the voltage by some angle $\phi$, depending on the relative proportions of the reactance and the resistance of the circuit.

We also know that the voltage V is doing two duties :—

(*a*) It is supplying a component $E_1 = IR$, to force the current through the resistance of the circuit. This component is in phase with the current.

(*b*) It is supplying a component $E_2 = \omega LI$, to overcome the counter E.M.F. of the inductance. This component is 90° ahead of the current.

Now the only expenditure of power in the circuit is in connection with the resistance.

In the case of the inductance, the energy expended in creating a magnetic field round the inductance is restored perfectly to the machine when the magnetic field collapses.

In fact, we may say that although the machine has to do work on the inductance when it is creating the magnetic field round it, when the magnetic field collapses, the machine is driven as a motor, and "has a lift."

So that the introduction of the inductance involves no expenditure of energy, and the only power required from the mains is that necessary to force the current through the resistance of the circuit.

Hence the power expenditure is equal not to VI, but to $E_1 \times I$, where $E_1 = IR$.

If we know the values of the current and of the resistance of the circuit, we may say at once that the power required $= E_1 \times I = IR \times I = I^2 R$.

If, however, we only know the applied voltage, the current, and the phase angle, we may arrive at the same result by saying—

$\frac{E_1}{V}$ is the cosine of the angle $\phi$ (*see* Fig. 132 (*a*) ).

Hence, $E_1 = V \cos \phi$, and the power required will be $E_1 \times I = VI \cos \phi$.

It will be equal to $\frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} \cos \phi = \frac{V_m I_m}{2} \cos \phi$, if maximum values are taken.

**261.** If the voltmeter and ammeter readings are multiplied together—*i.e.*, $V \times I$ — the product is termed the "**Apparent Watts,**" for this is the value of the power that is **apparently** being expended on the circuit.

The expression $VI \cos \phi$ is known as the "**True Watts,**" for this is the power really required from the mains.

The expression "$\cos \phi$" is known as the "**Power Factor**" of the circuit.

The Power Factor may be arrived at in several ways :—

(*a*) Since the Apparent Watts = VI, and the True Watts $VI \cos \phi$, then $\cos \phi = \frac{\text{True Watts}}{\text{Apparent Watts}}$.

(*b*) Since $V = IZ$ and $E_1 = IR$—

$$\text{Cos}\ \phi = \frac{E_1}{V} = \frac{IR}{IZ} = \frac{R}{Z}.$$

This method of arriving at the power required by the circuit is equally true if the circuit contains capacity and resistance, or capacity, resistance and inductance.

The energy stored up in the condenser, when it is charged up, is restored perfectly to the circuit when the condenser discharges, so that, as before, the only expenditure of energy is in connection with the resistance, and power is required from the mains solely on this account.

**Example 39.**

**Find the Power Factor, True Watts, and Apparent Watts for the circuit given in Example 31 above.**

True Watts $= I^2 R = 2{\cdot}97^2 \times 10 = 88{\cdot}21$ watts.

Apparent Watts $= VI = 50 \times 2{\cdot}97 = 148{\cdot}5$ watts.

$$\text{Power Factor} = \cos\phi = \frac{R}{Z} = \frac{10}{16{\cdot}83} = {\cdot}5941.$$

or, True Watts $= VI \cos\phi = 50 \times 2{\cdot}97 \times {\cdot}5941 = 88{\cdot}21$ (again).

$$\text{or, Power Factor} = \frac{\text{True Watts}}{\text{Apparent Watts}} = \frac{88{\cdot}21}{148{\cdot}5} = {\cdot}5941.$$

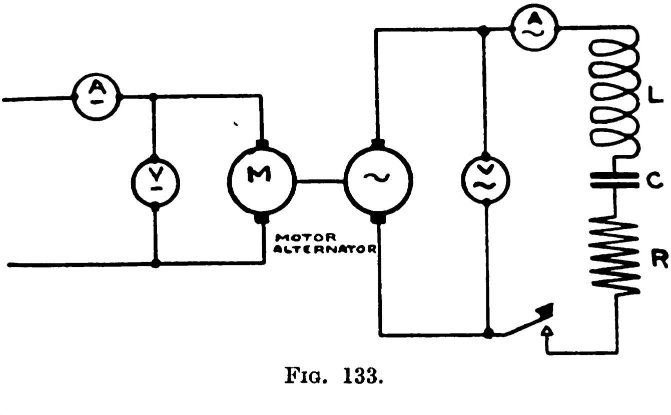


Fig. 133.

**262.** If we have measuring instruments joined up to a motor alternator, as illustrated in Fig. 133, then the ammeter and the voltmeter on the A.C. side will read the apparent watts, while the ammeter and the voltmeter on the D.C. side will give a measure of the true power being expended on the circuit, together with the power required to overcome the frictional losses of the machine.

If a reading of the D.C. ammeter be taken with the machine running, but with the A.C. circuit broken, and another reading when the A.C. circuit is completed, the power factor can be calculated.

**Example 40.**

The following results were obtained from a motor alternator :—

| D.C. Motor side. | | A.C. side. | |
|---|---|---|---|
| Ammeter. | Voltmeter. | Ammeter. | Voltmeter. |
| 30 | 220 | 0 | 320, key not pressed. |
| 60 | 220 | 50 | 300, key pressed. |

The power required for revolving the machine—

$$= 30 \times 220 = 6{,}600 \text{ watts.}$$

The total power required—

$$= 60 \times 220 = 13{,}200 \text{ watts.}$$

Hence the True Power required for the A.C. circuit alone = 13,200 − 6,600 = 6,600 watts (neglecting the extra copper losses at the higher load).

The Apparent Watts = 50 × 300 = 15,000.

$$\text{Hence the Power Factor} = \frac{\text{True Watts}}{\text{Apparent Watts}} = \frac{6{,}600}{15{,}000} = \cdot 44.$$

**263.** If the circuit contains nothing but resistance, or **if it is in resonance with the applied frequency,** then current and volts are entirely in phase, cos $\phi = 1$, and the Apparent and True Watts are equal, for then no voltage has to be devoted to balancing the counter E.M.F.'s of inductance and capacity, and the full A.C. voltage is devoted to forcing the maximum possible current through the resistance of the circuit.

On the other hand, if the circuit contains inductance and capacity only, and no resistance, there is no expenditure of energy required at all whether there is resonance or not, currents and volts are 90° out of phase, and cos $\phi = 0$.

A good analogy for this condition is as follows :—Imagine a workman who is sometimes diligent and sometimes lazy in an untidy workshop where the tools are frequently lost. If he cannot find his tools just at the moment when he is inclined to work, or again if he discovers them when he is inclined to be lazy, he will not in either case do useful work. The phase-difference between the possession of tools and inclination to work brings about a working result of zero value, although there is sometimes inclination to work and sometimes there are tools.

If the phase-difference is not quite as great—that is to say, if the man finds his tools just before he has lost his inclination to work—the result will not, of course, be quite nothing, but it will be less than if the possession of tools and full inclination to work were simultaneous.

**264. Rating of Alternators.**—Makers of alternating current machines rate their machines as being capable of delivering so many kilo-volt ampères (k.V.A.) and not as capable of delivering so many kilo-watts (kw.).

That is to say, they guarantee that the machine will generate a certain voltage if kept revolving at the correct speed, and that it will stand a certain current without overheating.

They cannot guarantee it as being capable of producing a certain power under all conditions, because they do not know the nature of the load the user is going to put on it.

For example, if a machine guaranteed to deliver 5 kW. at 200 volts were put on to a circuit having a power factor of ·7, it would then have to supply an apparent power of $\frac{5{,}000}{\cdot 7} = 7{,}143$ watts, so that the True Watts (5,000) should be equal to the Apparent Watts (7,143) multiplied by cos $\phi$ (·7).

This would necessitate a current of $\frac{7{,}143}{200} = 35{\cdot}7$ amps. instead of $\frac{5{,}000}{200} = 25$ amps.

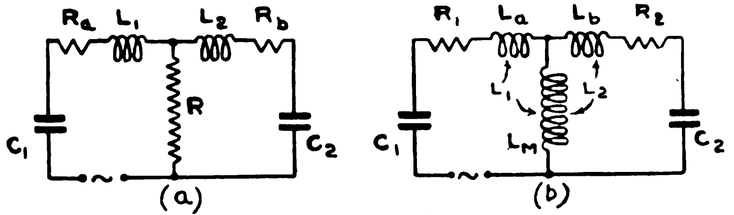
This is their method of safeguarding their own interests.

## COUPLED CIRCUITS.

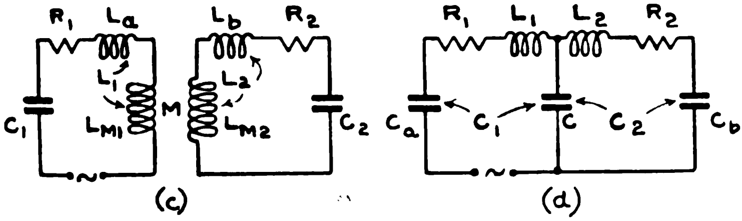
**265. Methods of Coupling.**—When two circuits are so arranged that current or E.M.F. in either produces a current or E.M.F. in the other, they are said to be coupled.

The two circuits may influence one another in several ways :—

(*a*) **By resistance coupling.**—When a resistance is common to both circuits. The voltage drop due to the current in one circuit flowing through the resistance acts as an applied E.M.F. in the other (Fig. 134 (*a*) ).



(a) RESISTANCE COUPLING (b) AUTO- INDUCTIVE COUPLING



(c) INDUCTIVE COUPLING (d) CAPACITY COUPLING

*Coupled Circuits.*

FIG. 134.

(*b*) **By auto-inductive coupling,** when a part of the inductance of the two circuits is common.

The current in each circuit flows through this common part, and the induced E.M.F. due to the change of the current is acting as an E.M.F. of self induction in the one circuit, but as an externally applied E.M.F. in the other (Fig. 134 (*b*)).

(*c*) **By inductive coupling,** that is, by the magnetic flux from each inductance interlinking with the turns of the other inductance (Fig. 134 (*c*)).

(*d*) **By capacity coupling,** when a part of the capacity is common to both circuits. As a result of the current in one circuit there will be a voltage variation across the common condenser.

This voltage variation acts as an applied E.M.F. to the second circuit (Fig. 134 (*d*)).

(*e*) By various combinations of the above.

**266.** In all cases $L_1$, $L_2$, $C_1$, $C_2$, $R_1$, $R_2$ represent the total inductance, capacity and resistance in the primary and secondary circuits. $L_a$, $L_b$, $C_a$, $C_b$, $R_a$, $R_b$ represent the inductances, capacities and resistances not taking any part in the transference of energy.

We will assume that in all cases, the circuits $L_1$, $C_1$ and $L_2$, $C_2$ are tuned individually to the same LC value, which corresponds to the frequency of the voltage applied to the primary, since this is the case in which we are most interested.

Thus in all cases $I = \frac{V}{R}$, where V is the voltage impressed on the circuit, and R is the total resistance included in the circuit.

**267. Case (a). Resistance Coupling** (Fig. 134 (*a*)).—The primary current $I = \frac{V}{R_1} = \frac{V}{R_a + R}$ since $R_a$ and R are both included in the primary.

The voltage impressed on the secondary is the ohmic drop across R; *i.e.*, $E_2 = I_1R$.

Hence $I_2 = \frac{I_1 R}{R_b}$.

The resistance of the combination as it affects the supply source is that of the primary and secondary resistances in parallel, *i.e.*, $\frac{R_1 R_b}{R_1 + R_b}$, where $R_1 = R_a + R$.

**Case (b). Auto-Inductive Coupling** (Fig. 134 (*b*)).—
$L_1 = (L_a + L_M)$ and $L_2 = (L_b + L_M)$.

The primary current, which flows through $L_M$, is $I_1 = \frac{V}{R_1}$.

The voltage acting on the secondary circuit is that across $L_M$; *i.e.*. $E_2 = \omega L_M I_1$.

The secondary current $I_2 = \frac{E_2}{R_2} = \frac{\omega L_M I_1}{R_2}$.

The presence of $R_2$ in the secondary will have the effect of increasing the load thrown on the supply source.

Let us determine the **equivalent or effective resistance** of $R_2$ as it affects the primary.

The watts expended in the secondary

$$= I_2^2 R_2 = \left(\frac{\omega L_M I_1}{R_2}\right)^2 \times R_2 = \frac{I_1^2 \times (\omega L_M)^2}{R_2}.$$

The power expended in the primary $= I_1^2 \times R_1$.

Therefore the total power expenditure $= I_1^2 \times \left(R_1 + \frac{(\omega L_M)^2}{R_2}\right)$.

The resistance of the whole circuit thus $= R_1 + \frac{(\omega L_M)^2}{R_2}$, and the effective resistance of $R_2$ as it affects the primary $= \frac{(\omega L_M)^2}{R_2}$.

From this we conclude that the greater the value of the common inductance $L_M$, and the smaller $R_2$, the greater the load thrown on the supply source.

**Case (c). Inductive Coupling** (Fig. 134 (*c*)).—The question of mutual induction and mutual inductance has already been referred to in Chapter III., para. **119** *et seq.*

When two coils, each of a certain self inductance, are placed at such a distance apart that a current changing through one at the rate of one ampère per second generates in the other an E.M.F. of one volt, the two coils are said to have unit mutual inductance (M) of **one henry.**

Thus the voltage induced in one circuit = M × rate of change of current in the other.

In Fig. 134 (*c*) above, the two coils taking part in the mutual inductive action are denoted as $L_{M1}$ and $L_{M2}$.

The voltage induced across $L_{M2} = E_2 = M \times \omega I_1$.
The voltage induced across $L_{M1} = E_1 = M \times \omega I_2$.

The secondary current $I_2$ is equal to $\frac{\omega M I_1}{Z_2}$ in the general case, and to $\frac{\omega M I_1}{R_2}$ in the special case of resonance we are now considering.

The effect of the secondary resistance $R_2$ upon the primary circuit may be arrived at in exactly the same manner as before.

The watts expended in the secondary circuit

$$= I_2^2 \times R_2 = \left(\frac{\omega M I_1}{R_2}\right)^2 \times R_2 = I_1^2 \times \frac{(\omega M)^2}{R_2}.$$

Therefore the effective resistance of the secondary as it affects the primary $= \frac{(\omega M)^2}{R_2}$.

**268.** Let us take a simple example of mutual inductance which will be familiar to all readers who have had any practical experience of W/T, viz., that of an ammeter coupled to an oscillatory circuit through an ammeter transformer.

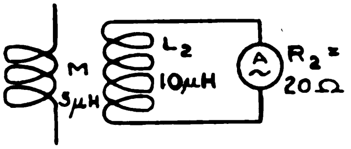


FIG. 135.

**Example 41.**

Let the primary current $I_1$ be 10 amps, the mutual inductance M be 5 mics, the secondary inductance $L_2$ be 10 mics, the resistance of the ammeter $R_2$ be 20 ohms, and let $\omega$ be equal to $10^6$ radians per second.

$$\text{Then } E_2 = \omega M I_1 = 10^6 \times \frac{5}{10^6} \times 10 = 50 \text{ volts.}$$

$$X_2 = \omega L_2 = 10^6 \times \frac{10}{10^6} = 10 \text{ ohms.}$$

$$Z_2 = \sqrt{R_2^2 + X_2^2} = \sqrt{20^2 + 10^2} = \sqrt{500} = 22{\cdot}37 \text{ ohms.}$$

$$I_2 = \frac{E_2}{Z_2} = \frac{50}{22{\cdot}37} = 2{\cdot}237 \text{ amps.}$$

Hence the ammeter reading will be 2·237 amps, when the primary current is 10 amps.

**269. Coupling Factor.**—When two circuits are coupled together, they react upon one another, so that the current in each circuit is not the same as would be the case were the other circuit absent. The extent of the reaction is, however, very different in different cases.

Circuits are said to be "closely or tightly" coupled when any change in the current in one is able to produce considerable effects in the other.

When either circuit is little affected by the other, the coupling is regarded as "loose."

A more exact measure of the closeness of the coupling is given by what is called the "co-efficient of coupling," denoted by the letter **k**.

If two circuits are coupled by reason of **mutual inductance** so closely that every line of force produced by $L_1$ also threads through $L_2$, and *vice versâ*, this is the case of perfect coupling.

If, on the other hand, the circuits are so arranged that only a portion of the flux of either interlinks with the other, then the coupling is expressed by a factor "k" which expresses the actual coupling that exists compared to the coupling there might have been had it been perfect.

We have already seen in Chapter III., para. **123** that M varies as $\sqrt{L_1L_2}$, or that $M = k\sqrt{L_1L_2}$, where k is a constant.

**Thus k (the coupling factor) in the case of mutual inductive coupling** $= \dfrac{M}{\sqrt{L_1L_2}}$.

Calling the maximum coupling factor unity (k = 1) we have, for perfect coupling, $M = \sqrt{L_1L_2}$; if the coupling is not perfect, then k is some fraction less than unity.

**In the case of auto-inductive coupling,**

$$k = \frac{L_M}{\sqrt{L_1L_2}} = \frac{L_M}{\sqrt{(L_a + L_M)(L_b + L_M)}} \text{ (Fig. 134 } (b)).$$

**In the case of capacity coupling,**

$$k = \frac{\sqrt{C_1C_2}}{C} \text{ (Fig. 134 } (d)).$$

But in the primary $C_a$ and C are in series; therefore $C_1 = \dfrac{C_a \times C}{C_a + C}$.

Similarly $C_2 = \dfrac{C_b \times C}{C_b + C}$.

$$\text{Therefore } k = \sqrt{\frac{\dfrac{C_aC}{C_a + C} \times \dfrac{C_bC}{C_b + C}}{C}} = \sqrt{\frac{C_aC_b}{(C_a + C)(C_b + C)}}.$$

**270.** In the case of inductive coupling, the coupling between two circuits may be varied in one of two ways :—

(*a*) By moving the two coils closer together.

(*b*) By increasing the inductance of the two coils which take part in the mutual inductive action, and decreasing the inductance of the two coils which do not so take part, in order to maintain resonance in both circuits.

For example, in a spark transmitting circuit (*see* para. **324**), the coupling of the aerial to the primary may be increased by :—

(*a*) pushing the "mutual" closer to the primary;
(*b*) adding some turns on the mutual coil and taking some turns off the aerial coil.

**271. The Double Frequency Effect.**—We get a very curious effect in the case of two coupled circuits when they are set in oscillation and then allowed to react freely upon each other. The effect is more marked the tighter the coupling. The spark transmitting circuit is an example of this.

Suppose that the two circuits $L_1$ $C_1$ and $L_2C_2$, Fig. 136, are tuned to the same LC value, and suppose that the primary circuit $L_1C_1$ is set in oscillation by some means, and that the whole combination is then allowed to oscillate freely at some rate that pleases it.

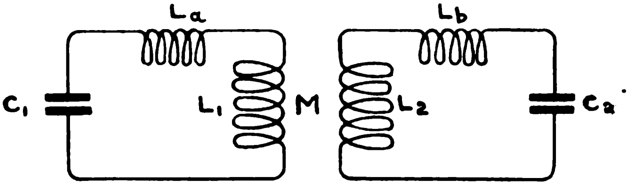


FIG. 136.

It might naturally be supposed that each circuit would oscillate at a frequency $f = \frac{1}{2\pi\sqrt{L_1C_1}} = \frac{1}{2\pi\sqrt{L_2C_2}}$, but this is not so.

It is found that the reactance of either circuit is zero, that is, the impedance is minimum, for two different frequencies;

$$f' = \frac{f}{\sqrt{1+K}} \text{ and } f'' = \frac{f}{\sqrt{1-K}}.$$

Thus f′ is a frequency lower than, and f″ a frequency higher than f, the frequency at which either circuit would oscillate when separated from the other.

This may be proved as follows :—

In the circuits under discussion, $L_1C_1 = L_2C_2 = L_0C_0$: *i.e.*, $L_0C_0$ = the LC value of either circuit taken separately. Let $\omega$ equal $2\pi$ x the frequency at which either circuit will oscillate when the two are coupled together.

Let $LC = \frac{1}{\omega^2}$, *i.e.*, **the apparent LC value** of either circuit when coupled to the other one.

$E_2$ (the voltage impressed on the secondary by the primary) = $\omega MI_1$ (*a*)

$$I_2 = \frac{E_2}{\omega L_2 - \frac{1}{\omega C_2}} = \frac{\omega MI_1}{\omega L_2 - \frac{1}{\omega C_2}} \qquad (b)$$

$E_1$ (the voltage impressed on the primary by the secondary) = $\omega MI_2$ (*c*)

and $$I_1 = \frac{E_1}{\omega L_1 - \frac{1}{\omega C_1}} \qquad (d)$$

But $E_2 = E_1$ (Chapter III., p. 71).

$$\text{Hence } I_2 = \overset{(c)}{\frac{E_1}{\omega M}} = \overset{(d)}{\frac{I_1\left(\omega L_1 - \frac{1}{\omega C_1}\right)}{\omega M}} = \overset{(b)}{\frac{\omega MI_1}{\omega L_2 - \frac{1}{\omega C_2}}}.$$

Thus $(\omega M)^2 = \left(\omega L_1 - \frac{1}{\omega C_1}\right) \left(\omega L_2 - \frac{1}{\omega C_2}\right).$

Divide by $\omega^2 L_1 L_2$.

$$\frac{M^2}{L_1L_2} = \frac{\omega L_1 - \frac{1}{\omega C_1}}{\omega L_1} \quad \frac{\omega L_2 - \frac{1}{\omega C_2}}{\omega L_2}$$

$$= \left(1 - \frac{1}{\omega^2 L_1 C_1}\right) \left(1 - \frac{1}{\omega^2 L_2 C_2}\right).$$

Substitute $\frac{1}{LC}$ for $\omega^2$, and $L_0C_0$ for $L_1C_1$ and $L_2C_2$.

$$\frac{M^2}{L_1L_2} = \left(1 - \frac{LC}{L_0C_0}\right) \left(1 - \frac{LC}{L_0C_0}\right) = \left(1 - \frac{LC}{L_0C_0}\right)^2.$$

Hence $$\frac{M}{\sqrt{L_1L_2}} = \pm \left(1 - \frac{LC}{L_0C_0}\right)$$

or $$LC = L_0C_0 \left(1 \pm \frac{M}{\sqrt{L_1L_2}}\right) = L_0C_0\,(1 \pm k).$$

Thus $L_0C_0$ has two apparent values :—

$$L_0C_0\,(1 + k) \text{ and } L_0C_0\,(1 - k).$$

If f′ is the frequency corresponding to $L_0C_0\,(1 + k)$.
f″ ,, ,, ,, ,, ,, $L_0C_0\,(1 - k)$.
f ,, ,, ,, ,, ,, $L_0C_0$.

Then $$f' = \frac{f}{\sqrt{1 + k}} \text{ and } f'' = \frac{f}{\sqrt{1 - k}}.$$

This matter will be referred to further in Chapter VII.

**272. Forced Oscillations.**—In the cases we considered in paras. **266** and **267**, where a sine E.M.F. of frequency f is applied to the primary, the currents in the two circuits, primary and secondary, are at first very complicated, consisting of oscillations of the two frequencies f′ and f″ superimposed upon forced waves of frequency f.

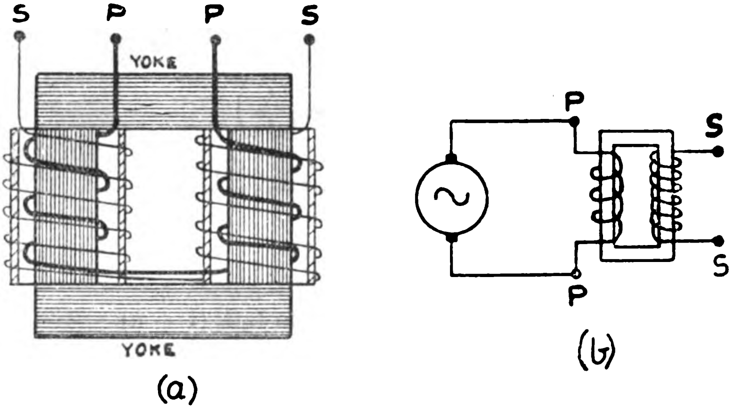
The free oscillations quickly die away, however, and there remain sine currents of frequency f in both primary and secondary.

## CHAPTER VI.

## THE TRANSFORMER.

**273.** One of the most important advantages of alternating currents over continuous currents is the extreme ease with which the transformation from a low to a high voltage, or *vice versâ*, may be accomplished.

Such transformation is effected by means of **Transformers,** whose efficiency exceeds that of any other electrical apparatus.



*The Transformer.*

FIG. 137.

**274. Construction of Typical Transformer.**—Two **iron cores** made of thin sheets of laminations of iron, averaging about ·012-inch thick, are built up, each sheet being slightly japanned or oxidised. The ends of the iron cores are connected by two iron yokes constructed in the same manner.

On each core is wound a coil of insulated copper wire, called the **Primary;** these two coils are connected in series, as illustrated in Fig. 137 (*a*).

The primary windings are covered with insulating sleeves, made of good insulating material—micanite, mica, or presspahn.

Over these again are wound the Secondary Coils, which have more turns than the Primary if the alternating voltage is to be increased.

The two secondary windings are joined in series, and their ends are brought to two terminals heavily insulated with ebonite or porcelain.

**275. Primary E.M.F.**—If an alternator is connected up to the primary terminals, and the secondary terminals are left disconnected or on "open circuit," as illustrated diagrammatically in Fig. 137 (*b*), then an alternating current will pass through the primary winding, and an alternating flux will be set up in the core.

Since the primary winding has a great many turns, and the magnetic path for the lines of force is a very good one, the inductance of the primary with the secondary on open circuit will be a very large value, of the order of several henries.

The applied voltage of the alternator will have to do two things :—

(1) Cause the current to flow through the resistance of the primary winding.

(2) Balance the induced E.M.F. in the primary winding due to its self induction.

We learnt in the preceding chapter that, in any circuit comprising inductance and resistance only, $I = \frac{V}{\sqrt{R^2 + (\omega L)^2}}$; this formula applies here, where I is the magnetising current flowing from the alternator through the primary, V the voltage of the alternator, L the inductance and R the resistance of the primary winding.

The inductance of the primary is, however, so great compared to its resistance, that the voltage necessary for overcoming the latter may be neglected. Let $L_1$ denote the inductance of the primary winding, $L_2$ the inductance of the secondary winding and $I_M$ the magnetising current. The current $I_M$ is here equal to $\frac{V}{\omega L_1}$, and the alternator voltage V is exactly balanced by the induced E.M.F. of the primary, *i.e.*, $V = \omega L_1 I_M$ volts.

$I_M$, the magnetising current, will be lagging by 90° on the alternator E.M.F.

These facts are expressed in the following vector diagram :—

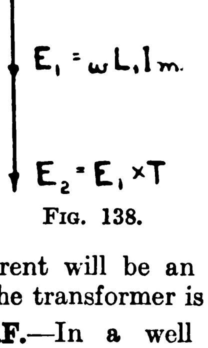


FIG. 138.

The magnetising current will be an exceedingly small one, since the impedance of the transformer is so great.

**276. Secondary E.M.F.**—In a well designed transformer, practically all the flux due to the current flowing through the primary will cut every turn of the secondary winding also, as it expands and collapses round the primary winding.

From this it follows that the E.M.F. induced in each turn of the secondary is equal to that induced in each turn of the primary, so that the ratio of the total primary to the total secondary E.M.F. is simply equal to the **ratio of the number of primary turns to the number of secondary turns.**

We may again neglect the voltage drop in the secondary due to resistance, since this is negligibly small compared to the inductance of the secondary, so that we have approxiately :—

$$\frac{\text{Primary P.D.}}{\text{Secondary P.D.}} = \frac{\text{Primary turns}}{\text{Secondary turns}}.$$

Thus the P.D. across the secondary is greater or less than the P.D. across the primary accordingly as the secondary has more or less turns than the primary.

For wireless purposes we always use a transformer with more secondary than primary turns, and therefore the applied voltage is increased by means of the transformer.

The ratio of secondary to primary turns is spoken of as the **transformation ratio,** or the step-up of the transformer, *i.e.*, a transformer with 100 primary turns and 1,000 secondary would have a transformation ratio or step-up of $10/_1 = 10$.

The transformation ratio is denoted by the letter " T."

Since the secondary voltage of the transformer is the *induced* E.M.F. due to the alternating flux set up by the primary current $I_M$, the secondary voltage ($E_2 = E_1 \times T$) is 180° out of phase with the voltage applied to the transformer by the alternator, as shown in Fig. 138.

As an example, let us take a transformer with 100 primary turns, supplied by an alternator giving an alternating supply of 100 volts.

Leave the secondary on open circuit.

Then the counter E.M.F. produced in the primary coil will be nearly as much as 100 volts—say, perhaps, 99 volts or even a little more.

For, since the lines of force are passing entirely through iron, we want only a small number of ampère-turns for magnetising the iron. Hence a very small pressure difference between primary P.D. and counter E.M.F. is required for sending this small magnetising current through the low resistance of the coil.

Since now in the 100 turns of the primary winding a counter E.M.F. of nearly 100 volts is produced, the counter E.M.F. of each turn will be nearly 1 volt.

Again, each turn of the secondary winding will have the same voltage induced in it as each turn of the primary winding, for both are traversed by the same magnetic flux.

The voltage produced in any turn of the secondary winding will, therefore, be equal to 1 volt.

If, for example, the secondary winding consists of 10 turns, its voltage will be about 10, with 100 turns about 100 volts, with 1,000 turns about 1,000 volts, &c.

### 277. Primary and Secondary Currents.

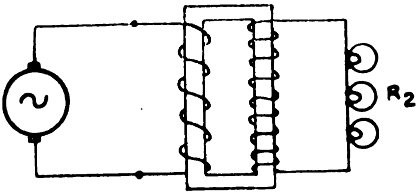


FIG. 139.

Let us join a non-inductive resistance $R_2$ across the secondary terminals—for instance a number of lamps in series, as in Fig. 139.

A secondary current will flow in phase with the secondary voltage $E_2$.

This current $I_2$ will be equal to $\frac{E_2}{R_2}$.

Any magnetic flux set up by an alternating current flowing through a coil of wire is proportional to the current flowing and the number of turns of wire through which it flows.

Now $I_2$ at each alternation flows through the secondary winding and will therefore cause a magnetic flux due to $N_2 I_2$ ampère-turns in the iron core.

By Lenz's law this secondary flux is in opposition to the flux due to the primary current. Thus part of the primary flux is cancelled.

The effect of this is that the counter E.M.F. of self induction in the primary is reduced, and in consequence a greater current will be admitted through the primary.

Thus the alternator is supplying more current (*i.e.*, more power) to cope with the load on the secondary.

The same effect takes place in the secondary : *i.e.*, the primary and secondary fluxes act and react on one another.

As the secondary load is increased, we have a decrease of primary flux, an increase of primary current, and a decrease of induced E.M.F.'s in primary and secondary, since they both depend upon the primary current.

There is, therefore, an apparent decrease in inductance in both primary and secondary. **When full load conditions are reached the transformer primary and secondary windings will have apparently no inductance at all.**

The primary current will be limited only by the resistance of the primary winding and by the power output of the alternator.

The increase of primary current tends to cause a stronger flux, but this tendency is counteracted by the fact that the secondary current is tending to produce a flux in the opposite direction.

The result is that the difference between the primary and secondary flux remains constant whatever current is being taken from the transformer, provided the voltage of the alternator remains constant.

**278.** Having cleared the ground by this preliminary explanation, let us look into the matter a little more closely.

When the secondary circuit is open, the primary current adjusts itself to such a value that the E.M.F. due to the alternating flux just balances the applied P.D.

Now this balance of alternator P.D. and counter E.M.F. must also—still neglecting the resistance drop—be maintained when the transformer is loaded.

In order, therefore, to maintain the original value of the alternating flux corresponding to the given primary P.D., the resultant ampère-turns must be maintained constant.

But this condition obviously implies that in the primary there must, in addition to the current which existed on open secondary circuit, be a further component of current—the **load** component—which has a value such that the ampère-turns due to it just suffice to wipe out the ampère-turns of the secondary, leaving a constant value for the resultant ampère-turns.

We may speak of the inoperative ampère-turns (those balancing the secondary ampère-turns) as the **load ampère-turns,** and of the open circuit ampère-turns as the **magnetising** ampere-turns.

We then have the relation—

Prim. **load** ampère-turns = sec. ampère-turns.

or—

Prim. load current × prim. turns = sec. current × sec. turns.

So that—

$$\frac{\text{Prim. load current}}{\text{sec. current}} = \frac{\text{sec. turns}}{\text{prim. turns}}.$$

We have already stated that the primary magnetising current has a very small value: hence the **load ampère-turns** corresponding to full load may be taken to be equal to the **total** ampère-turns at full load, and the magnetising current may be disregarded.

Hence—

$$\frac{\text{prim. I}}{\text{sec. I}} = \frac{\text{sec. turns}}{\text{prim. turns}}, \text{ as above.}$$

If $I_1$ and $I_2$ denote the primary and secondary currents, $E_1$ and $E_2$ the primary and secondary E.M.F.'s and $N_1$ and $N_2$ the turns of the primary and secondary windings, we have :—

$$E_2 = E_1 \times \frac{N_2}{N_1} = E_1 \times T,$$

where T is the transformation ratio,

$$\text{and } I_1 = I_2 \times \frac{N_2}{N_1} = I_2 \times T,$$

or, in other words, that the secondary voltage is greater than the primary voltage, and the primary current is greater than the secondary current, in the proportion of the transformation ratio.

Notice that, as we have neglected our losses, the watts taken out are equal to the watts put in, for

$$E_2 I_2 = E_1 \times T \times \frac{I_1}{T} = E_1 I_1.$$

Of course this statement cannot be literally true, and there must be a certain expenditure of energy in the transformer, as explained later.

**279.** The relative phases of current and voltage when the transformer is on a non-inductive load will be as follows :—

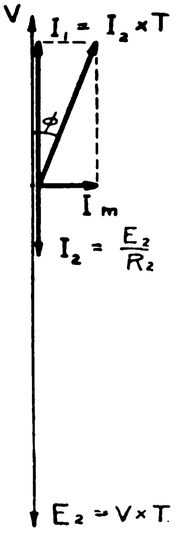


FIG. 140.

The applied voltage of the alternator (V) causes the magnetising current $I_M$ to flow, lagging 90° astern of it: the alternating flux set up by I through the core cuts the secondary winding and sets up the alternating voltage $E_2$ across its terminals equal to V multiplied by the transformation ratio T, and opposite in phase to V.

A secondary current $I_2$ flows through any resistance $R_2$ joined across the secondary, equal to $\frac{E_2}{R_2}$ and in phase with $E_2$.

This current $I_2$ has a demagnetising effect on the core, and to counter-balance it, a primary current $I_1$ must flow, greater than $I_2$ in the proportion of the transformation ratio, and opposite to it in phase, *i.e.*, in phase with V.

The alternator current I is shown as the resultant of these two—$I_1$ and $I_M$—lagging on the alternator P.D. by a small angle $\phi$.

The greater the secondary current, the greater does the primary current $I_1$ become in proportion to $I_M$, and the more nearly do the primary voltage and current get into phase.

Thus we see again that the transformer on full load appears, as a whole, to behave as if almost non-inductive, the voltages and currents of the primary and secondary respectively, being almost in phase.

### 280. Transformer on Reactive Load.

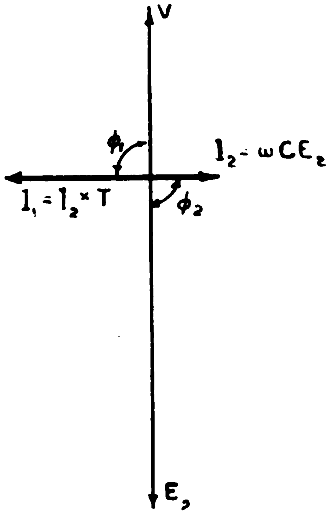


FIG. 141.

Suppose the resistance $R_2$ is replaced by a condenser C. Then the secondary current will lead the voltage $E_2$ by 90° as shown in Fig. 141, and will be equal to $\omega CE_2$.

To counter-balance this, the alternator will have to supply a current $I_1$, leading by 90°, and equal to $I_2 \times T$.

NOTE.—For clearness the magnetising current $I_M$ has been omitted in Fig. 141.

In order to get the alternator voltage and current into phase, an inductance will have to be added in the primary or secondary circuit of such a size as to make the tendency of the current to lag due to this inductance the same as its tendency to lead due to the condenser in the secondary circuit.

Inductances are used in W/T circuits for this purpose, and are termed "Impedance Coils" when joined in the primary circuit, or "Choking Coils" when joined in the secondary.

(The method by which the amount of inductance required is calculated is explained in Chapter VII.)

When this is the case, the circuit, so far as the alternator is concerned, possesses neither inductance nor capacity, provided the frequency of supply is not changed, and we return to the condition shown in Fig. 140, when the alternator has only the total effective resistance of the circuit to deal with.

**281. Magnetic Leakage.**—It is very nearly, but not quite, true that the whole of the flux in the iron core of the transformer passes entirely through both windings.

Actually the currents in the two windings will each cause a small amount of flux to pass through their own coils, which will not go through the coils of the other winding, but will pass round through the air spaces between the coils. This flux is known as **"Leakage" flux.**

The leakage flux from each winding will be produced by the current in that particular winding, and will not be due to the combined effects of the currents in the two windings together. This leakage flux will in each case therefore vary with the current in its own winding, and will cause the same effect **as self inductance in each of the windings.**

This will lead to a reduced secondary P.D. in somewhat the same way that the resistance of the windings causes it to decrease.

Some of the alternator P.D. will be used in overcoming this self-induction effect in the primary winding, and less will require to be balanced by the alternating flux.

Therefore less flux will be needed and less secondary E.M.F. will be induced.

Some of the secondary E.M.F. will be used in overcoming the self-induction effect of the secondary winding, so again reducing the amount available as the secondary P.D.

The leakage flux will thus cause the P.D. at the secondary terminals to fall off as the current increases.

It is to reduce this voltage drop that the transformer coils are wound one upon the other, as previously described. By this construction, the space available for the leakage flux is reduced to a minimum.

If the coils are arranged in any other way, as for instance, with the whole primary on one leg of the core and the secondary on the other, much larger paths would be available for the leakage flux and the falling off of the secondary terminal P.D. would be considerably increased.

A transformer then, when taking the full load current for which it is designed, has apparently only a very small self inductance—due to magnetic leakage—although the inductances of its primary and secondary windings taken separately are very great indeed.

**282. Copper Losses.**—The resistance of the primary and secondary windings must be taken into consideration.

If $R_1$ and $R_2$ are the resistances of the primary and secondary windings respectively, then the watts lost in the primary will be $I_1^2R_1$, and the watts lost in the secondary will be $I_2^2R_2$.

These losses are minimised by using large section copper wire or flat copper strip for the primary and secondary windings.

In order to keep down eddy current losses in the copper conductors they are often sub-divided, and made up of several insulated strands joined in parallel.

**283. Core Losses.**—Two sources of loss occur in the iron core, namely, eddy current losses and hysteresis losses.

**Eddy Current Losses.**—If the core were solid throughout, large circulating currents would be set up in it in the same plane as the direction of the windings, as indicated in Fig. 142 (*a*), which shows a cross section of one leg.

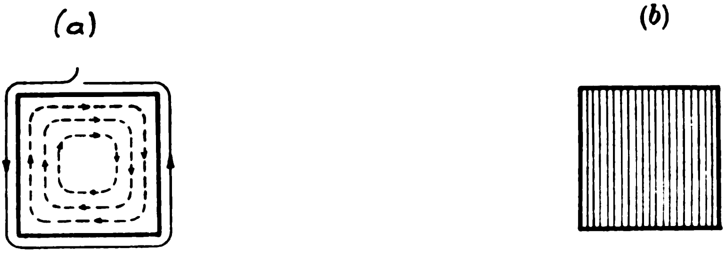


Fig. 142.

These currents are termed "**Eddy Currents.**"

They represent an expenditure of energy which would heat up the core unduly, and damage the insulation of the winding.

They are kept down to a very small value by "laminating" the cores and yokes as indicated in Fig. 142 (*b*), *i.e.*, making them up of a number of thin sheets of iron laid together and insulated from each other by varnish, shellac, or tissue paper.

In this manner the eddy currents are forced to travel in very narrow high resistance paths, and are kept down to such a small value that their effect is not serious.

The laminations are frequently "L" shaped, being pushed inside the coils from alternate ends.

**284. Hysteresis Losses.**—Whenever the alternating current through the primary winding reverses its direction, the direction of flux through the iron core is reversed.

Now, all iron has a certain tendency when once magnetised, to retain that magnetisation, and it requires a definite expenditure of energy on the part of the alternating current to reverse this magnetisation.

There is, therefore, a loss in the core for this reason—termed "**Hysteresis Loss**"—which appears in the form of heat.

The higher the frequency of the alternating current and the more dense the lines of force in the core the greater this loss will be.

Hard steel has greater hysteresis than soft iron.

Hence transformers have their cores constructed of soft iron, either pure or alloyed with a small percentage of silicon. The alloyed iron—known as "Stalloy"—is more expensive, but is found to cause considerably less hysteresis and eddy current loss.

**285. Efficiency of Transformers.**—In a well designed transformer, the expenditure of energy due to these various causes—magnetic leakage, copper losses, eddy current losses and hysteresis losses—is not very great.

The efficiency of a transformer is expressed as a percentage.

If $I_1$ and $E_1$ are the primary current and voltage, and $I_2$ and $E_2$ the secondary current and voltage, then the efficiency of the transformer per cent. $= \frac{I_2E_2}{I_1E_1} \times 100$, *i.e.*, efficiency $= \frac{\text{output}}{\text{input}} \times 100$: *e.g.*, if a transformer were said to have an efficiency of 95 per cent. this would mean that for every 95 watts taken from the secondary 100 watts would have to be supplied to the primary.

The following table gives the efficiencies which might reasonably be expected in modern transformers :—

| Output in kW. | 1 | 5 | 10 | 20 | 50 | 100 |
|---|---|---|---|---|---|---|
| Efficiency - | 94% | 95% | 95·5% | 96% | 96·5% | 97% |

From which we see that a transformer is an extremely efficient piece of apparatus.

**286. Connections of Windings.**—In transformers where the primary and secondary windings are arranged in two coils on the two legs of the core, the step-up varies according to whether the two primary and two secondary coils are joined in series or parallel.

For example, take a transformer with 100 secondary turns for every primary turn, then with—

| | |
|---|---|
| (*a*) Primaries in series, | Secondaries in parallel,<br>Step-up = 1 : 50. |
| (*b*) ,, ,, ,, | Secondaries in series,<br>Step-up = 1 : 100. |
| (*c*) Primaries in parallel, | Secondaries in parallel,<br>Step-up = 1 : 100. |
| (*d*) ,, ,, ,, | Secondaries in series,<br>Step-up = 1 : 200. |

In certain Service spark sets, arrangements (*a*) and (*b*) are used for convenience in charging the condenser. This is useful for maintaining resonance in the charging circuit, when a condenser is used which has two alternative values. The primary windings are connected permanently in series, and the secondaries are changed over from series to parallel by means of a switch, as illustrated in Fig. 144.

**287. Earth in Centre of Transformer.**—The centre point of the two secondary windings is always earthed, in large transformers, for the following reason:—

> Suppose we are getting a maximum voltage of 14,000 volts across the secondary of our transformer; that means that each terminal will alternately reach a pressure of 7,000 volts above and below "earth" potential or "zero."
>
> The thickness of the insulation on the secondary winding of the transformer is calculated so as to be sufficient, with a fair margin of safety, to stand this pressure.
>
> If now an earth leak were to develop on one side of the transformer, the terminal on this side would automatically be fixed at earth potential. The same flux is still cutting the secondary. Hence the potential of the other end of the winding would be alternating between 14,000 volts above and below earth instead of 7,000 volts, as in Fig. 143 (*a*).

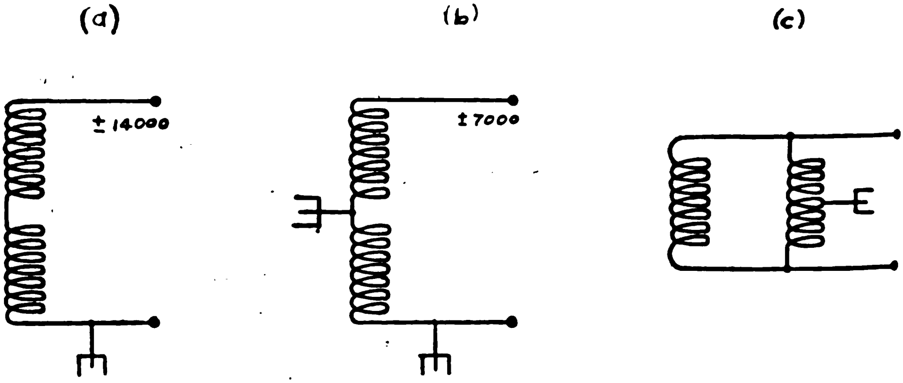


Fig. 143.

Since the casing and core of the transformer are connected to earth, it is evident that the insulation of the winding of the transformer secondary will be excessively strained at this point.

To obviate this, the centre point of the secondary winding is permanently connected to earth, as in Fig. 143 (*b*)—or, if the secondaries are in parallel, as in Fig. 143 (*c*)—which therefore prevents the outer ends reaching a greater potential above earth than their normal 7,000 volts.

Under these conditions, should an earth develop at one terminal of the winding, that half will be put on short circuit, and the secondary voltage will be only half its proper value; the short-circuited half of the secondary will call for a large primary current, and the A.C. cut-outs in the supply mains should blow.

Fig. 144 illustrates a Series-Parallel switch for earthing the centre point of the two windings when in the series position, as in Fig. 143 (*b*), and the centre point of one winding when in the parallel position, as in Fig. 143 (*c*).

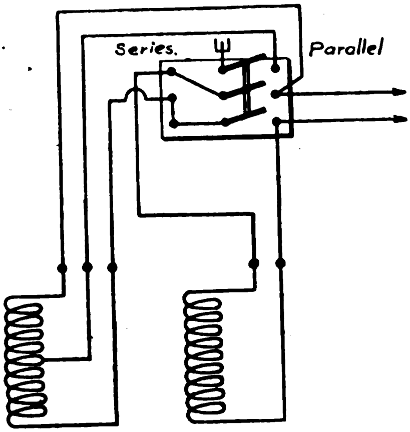


FIG. 144.

**288. Cooling of Transformers.**—It is necessary to make arrangements for radiating away the heat generated in the core and windings by the various losses referred to in sections 282, 283 and 284, as otherwise the insulation of the windings will be impaired.

This is effected by means of air or oil cooling.

In small transformers, the windings are merely enclosed in a well ventilated iron case, and the heat is radiated away by convection through the air.

Air cooling is cheap and clean, but the transformer must not be allowed to get damp, or the insulation of the high tension winding will suffer, nor must it be put away in a corner or covered up where no air will reach it or circulate round it.

Sometimes the case is filled with an insulating compound, in order to enable the clearance between the windings and casing to be decreased without fear of sparking over.

For oil cooling, the tank is filled with good insulating oil. The heat is then conveyed through the oil to the sides of the tank, and radiated away from there.

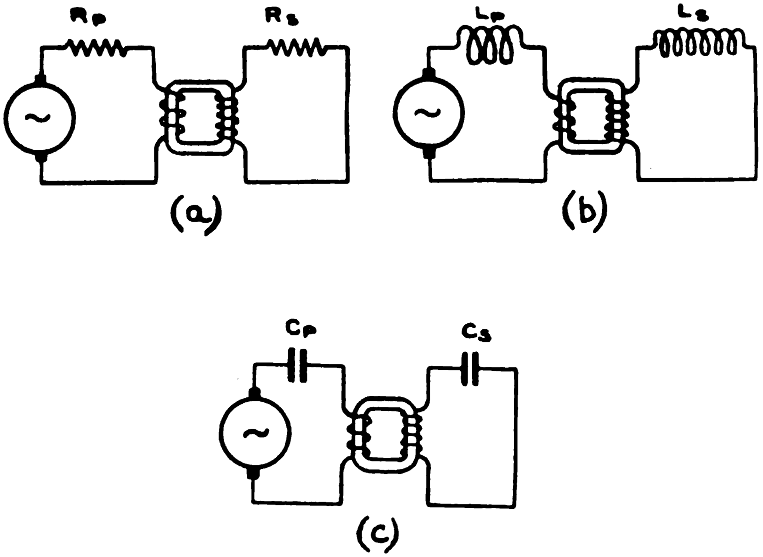
The oil protects the windings against damp, and the insulation of the windings is materially assisted by the presence of the oil.

It is necessary to make the lid of the tank perfectly airtight; otherwise the oil will absorb moisture from the atmosphere and lose its insulating property.

It is also necessary to arrange for the expansion of the oil when it becomes heated. This is done by providing an

"Expansion Tank," connected to the transformer case by a short length of pipe.

### 289. Equivalent Circuits.



*Equivalent Circuits.*
FIG. 145.

In considering circuits in which a transformer takes part, it is often convenient in calculations to reduce the circuit to an equivalent one in which the transformer is eliminated; that is, to find what value of R, L or C when connected on the primary side of the transformer, would give the same effect as the R, L or C which is actually connected on the secondary side.

(*a*) In the above circuit (Fig. 145 (*a*)) we have a resistance $R_s$ joined in series with the transformer secondary. This resistance will cause a certain energy expenditure.

We wish to determine the equivalent value of a resistance ($R_P$), which, when joined in series with the primary, will cause the same energy expenditure.

The watts expended in $R_S$, when traversed by the secondary current $I_2$, will be $I_2{}^2R_S$.

We wish to find what value $R_P$ should be so that $I_1{}^2R_P$ shall be equal to $I_2{}^2R_S$.

We know that $I_1 = I_2 \times T$: therefore $I_1{}^2 = I_2{}^2 \times T^2$.

$$I_1{}^2R_P = I_2{}^2R_S: \text{ therefore } R_P = \frac{I_2{}^2}{I_1{}^2}R_S = \frac{I_2{}^2}{I_2{}^2T^2}R_s = \frac{R_s}{T^2}.$$

Thus the equivalent value of $R_S$ when transferred to the primary side, is $\frac{R}{T^2}$.

(*b*) Let us replace $R_s$ by an inductance $L_s$ (Fig. 145 (*b*)) and find its equivalent value $L_P$.

The energy stored in the magnetic field of $L_s$ is equal to $\frac{1}{2} L_s I_2^2$ (para. 116).

The energy stored in the field of the equivalent inductance $L_P = \frac{1}{2} L_P I_1^2$.

By the same reasoning, it is clear that, in order to make $\frac{1}{2} L_P I_1^2$ equal to $\frac{1}{2} L_s I_2^2$, $L_P$ must be an inductance of such a value that $L_P = \frac{L_s}{T^2}$.

(*c*) Let us replace $L_s$ by a condenser C (Fig. 145 (*c*)).

The energy stored in the condenser $C_s = \frac{1}{2} C_s E_2^2$ (para. 130).

The energy stored in an equivalent condenser $C_P = \frac{1}{2} C_P E_1^2$.

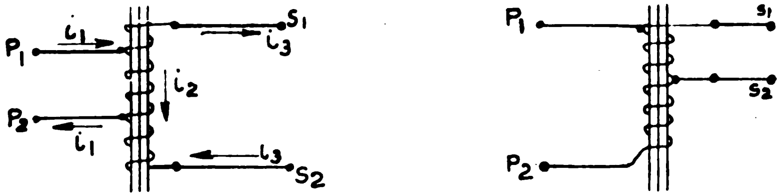
But $E_1^2 = \frac{E_2^2}{T^2}$ (paras. 255 and 257).

Therefore, to satisfy the condition that—

$$\frac{1}{2} C_P E_1^2 = \frac{1}{2} C_s E_2^2 : \ C_P = \frac{C_s E_2^2}{E_1^2} = C_s T^2.$$

That is, the equivalent value of $C_s$ when transferred to the primary side of the transformer, is $C_s \times T^2$.

**290. Auto-Transformer.**—This is a special type of transformer used for a small step-up or step-down of voltage.



STEP-UP.
(a)

STEP-DOWN.
(b)

FIG. 146.

It is a transformer with only one winding, as shown in Fig. 146 (*a*) and (*b*), and, having an iron-cored coil, possesses a large inductance.

To increase the alternator voltage, tappings are taken as shown in Fig. 146 (*a*), $P_1P_2$ being the primary terminals, and $S_1S_2$ the secondary terminals.

If an alternator is joined to $P_1P_2$ then its voltage will be balanced by the counter E.M.F. of the turns $N_1$, between the terminals $P_1P_2$.

The flux due to the primary current will thread the whole coil, and consequently the P.D. between the secondary terminals will be greater than the alternator voltage in the proportion of $\frac{N_2}{N_1}$.

The alternator current will be greater than the secondary current in the same proportion.

To step the voltage down, the transformer would be used as shown in Fig. 146 (*b*).

If a load is joined up across the secondary terminals $S_1$ $S_2$, currents will flow in the primary and secondary windings.

Let the primary current be $i_1$, the secondary current $i_3$, and the current through the common portion of the winding $i_2$.

At the instant shown let $P_1$ be positive to $P_2$. At the same moment $S_1$ will be positive to $S_2$, and the secondary current $i_3$ will flow in the direction indicated.

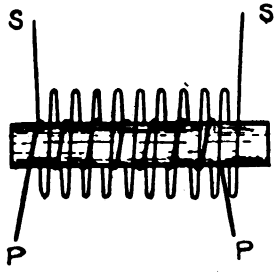
The current $i_1$ will divide at the tapping point, part going to supply the secondary current $i_3$ and part flowing through the common portion of the winding.

The current through this common portion will be the difference between the primary and secondary currents: *i.e.*, $i_2 = i_1 - i_3$.

An auto-transformer is unsuitable for a big step-up in voltage, as all low-tension apparatus and leads are in direct contact with the high-voltage winding; also part of the winding has to be thick enough to stand the full primary current and the whole insulated well enough to stand the full secondary voltage.

For these reasons an iron-cored auto-transformer is not used in wireless telegraphy for alternating currents, but the principle is an important one to understand, as it often comes in when considering, for example, how to join up aerial coils in oscillating circuits and in many other cases.

**291. Open-Core Transformers.**—By an "open-core" transformer is meant one where the iron magnetic circuit is not complete, as in the induction coil.



*Open Core Transformer*

FIG. 147.

Fig. 147 illustrates the primary and secondary windings of an induction coil.

Here the windings are wound over an iron core, but the return path for the magnetic lines of force consists of air, and magnetic leakage (and consequently the effective inductance on full load) is much greater.

**292. Air-Core Transformers.**—By this term is meant the various arrangements for transferring energy from one oscillatory circuit to another, in transmitting and receiving circuits, as described later.

The primary and secondary windings have no iron core through them, and their inductance is only of the order of microhenries, but the principles which govern the behaviour of the closed core transformer apply to them with certain limitations (paras. **267**, **310**).

## CHAPTER VII.

## THE OSCILLATORY CIRCUIT: SPARK SYSTEM.

**293.** Having read the foregoing chapters, we are now in a position to discuss how our original object may be obtained, viz., to produce a **high frequency disturbance in the æther.**

In the spark system of wireless telegraphy, this high frequency disturbance is effected by allowing a condenser to discharge freely across a spark gap, through an inductance.

Now it is essential to understand thoroughly how a circuit oscillates, as this is the most important question in the whole study of wireless telegraphy.

In reading the following chapters, it must be borne in mind that a circuit of inductance and capacity is just as ready to be set in vibration as are the balance wheel of a watch, the pendulum of a clock, a destroyer at sea, a violin string, or any other mechanical oscillator: all that is needed is a periodic supply of energy sufficient to make good the resistance (or frictional) losses.

We will first take a mechanical oscillator (Fig. 148) consisting of a weight and a spring. The spring is fixed in a horizontal position to a wall, and carries the weight on its free end.

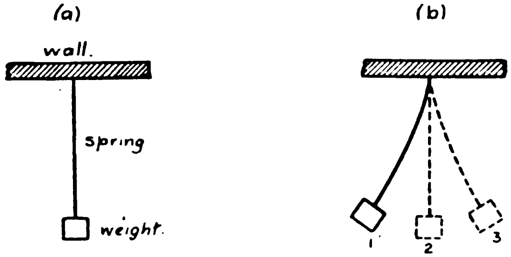


FIG. 148.

Imagine the weight to be pulled to one side, as in Fig. 148 (*b*) (1). The spring is bent, thereby storing up energy in itself, as it has a strong tendency to spring back again.

When it is released, it will spring straight, setting the weight in motion. The moving weight, owing to its inertia, will not stop dead when the spring has straightened (*b*) (2), but will continue past the middle position and swing to the right until its kinetic energy has been again stored up as potential energy in compressing the spring (*b*) (3).

It will then swing back again and will continue oscillating until the energy originally stored up in the spring when it was first bent has been expended in various frictional losses.

The rate at which the arrangement will oscillate will depend on the size of the weight and the length and elasticity of the spring. A short stiff spring and a small weight will oscillate much more rapidly than a long weak spring and a heavy weight.

The above is an exact analogy for the electrical oscillation of a condenser and inductance—the weight representing the inductance and the spring the condenser—and the reader should keep it in mind while reading the following paragraphs.

**295. The Oscillator.**—A spark oscillator consists of a condenser (C), an inductance (L), and a spark gap (G), as in Fig. 149, joined up to some suitable form of intermittent or alternating high voltage supply, which will be described in detail later. For the present we will merely assume that it is capable of charging the condenser C up to a high voltage at regular intervals.

> (*a*) Assume the condenser to be charged (as indicated in Fig. 149) with a charge of Q coulombs. Then the left-hand plate of the condenser and the upper spark plug will have a positive charge of electricity distributed uniformly over them, and an equal and opposite negative charge will be distributed over the right-hand plate, the surface of the inductance L, and the lower spark plug.

A state of electric strain, of $V_m\left(=\frac{Q_m}{C}\right)$ volts, will thus be produced between the plates of the condenser C and the plugs of the spark gap.

The energy stored in the condenser will be equal to $\frac{1}{2}CV_m^2$ joules.

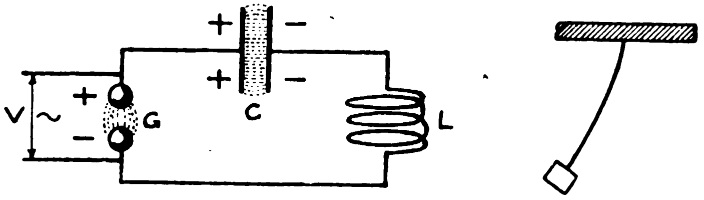


FIG. 149.

> (*b*) Assume that the spark gap G has been set to such a width that, when the charge put into the condenser has risen to its maximum value, the voltage across the gap is sufficient to break down the insulation of the air. Then the condenser will start to equalise the potential between its plates, and a current will flow from the left-hand plate across the gap, through the inductance L, to the right-hand plate.

A conductive bridge is set up between the spark plugs, composed of positive and negative ions of air, and small particles of copper driven off from the spark plugs. This constitutes a convection current.

After a small fraction of time the discharge will have equalised the potentials, and the electric strain across the condenser will have disappeared. But the current through the inductance will have set up a magnetic field round it, which will represent an amount of energy equal to $\frac{1}{2}LI^2$ joules (Fig. 150).

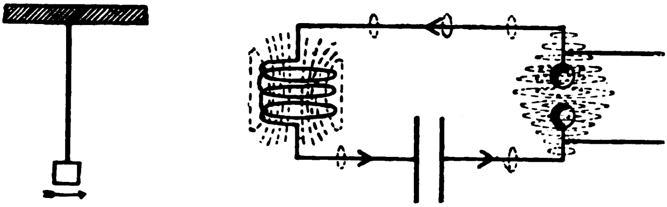


Fig. 150.

When the P.D. between the plates has fallen to zero the current through the inductance and its attendant magnetic field will have risen to a maximum. The energy originally stored in the condenser (where it set up an electric field between the plates) has now been transferred to the magnetic field round the inductance, *i.e.*, $\frac{1}{2}CV_m{}^2 = \frac{1}{2}LI_m{}^2$ assuming, for the moment, no losses in the circuit.

(*c*) When the P.D. between the condenser plates is equalised, there is no voltage left to keep the current flowing.

It will not, however, stop instantaneously, but will continue flowing while the magnetic field round the inductance is dying down, and consequently, when the magnetic field has completely died away, the condenser will be found to be charged once more, but now it will be charged positively on the right-hand plate, and negatively on its left-hand plate.

The energy stored in the magnetic field round the inductance has now been retransferred to the condenser and has produced a state of strain between its plates (Fig. 151).

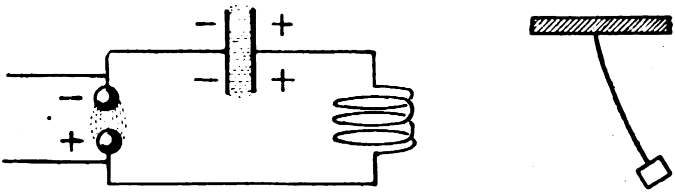


Fig. 151.

At the end of this third stage, the current flowing in the circuit has fallen to zero, and the voltage across the condenser and spark gap has risen to a maximum, but is of opposite sign to the original charge.

The conductive bridge between the spark plugs is not broken down at this moment, because the current immediately starts to rise again in the opposite direction.

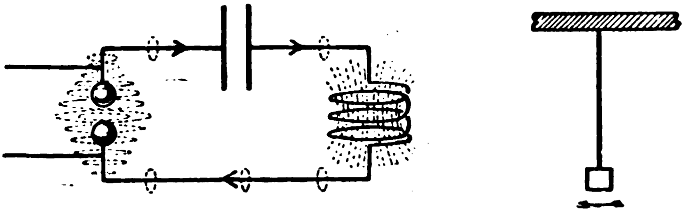


Fig. 152.

(*d*) The difference of potential thus again being built up, the condenser again discharges across the spark gap, but in the opposite direction to the first discharge. (Fig. 152.)

As before, after an interval of time the difference of potential and the electric strain have disappeared, the discharge has risen to a maximum, and a magnetic strain exists in the æther round the inductance and the other conductors composing the circuit.

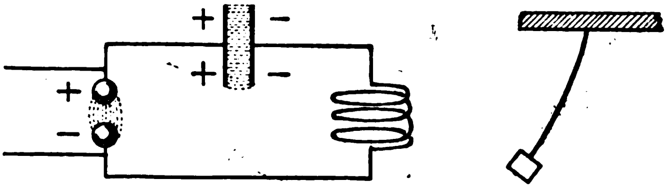


Fig. 153.

(*e*) Once again the magnetic field round the inductance dies away and charges up the condenser, in the same manner as it was originally charged (Fig. 153).

We have thus traced out one complete cycle of the oscillatory discharge.

**296. Relative Phases of Current and Voltage.** Fig. 154 illustrates the relative phases of the condenser current and voltage during the process just described.

The moment " R " in Fig. 154 corresponds with Fig. 149. The condenser is fully charged and no current is flowing out of it. Between " R " and " S " the P.D. across the condenser is falling and the current round the circuit is rising. At moment " S " (*see* Fig. 150) the condenser is completely discharged and the current has risen to its maximum value. Between " S " and " T " the condenser is becoming charged in the opposite direction, and the current into it gradually decreases because the increasing charge in the condenser renders it harder and harder for more coulombs to flow into it.

Moment " T " corresponds to Fig. 151, moment " U " to Fig. 152, moment " V " to Fig. 153, and so on.

From an inspection of Fig. 154, we therefore see that in an oscillatory discharge of a condenser, current and voltage are always 90° out of phase, the current being maximum when the voltage across the condenser is zero, and *vice versâ*.

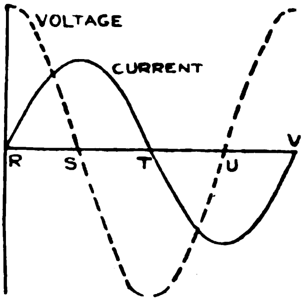


FIG. 154.

**297. Damping.**—This process of the transfer of energy from the electric field between the condenser plates to a magnetic field round the inductance and back again will continue for some time, and would continue indefinitely if there were no losses in the circuit.

Just as, however, in mechanics it is impossible to produce "perpetual motion" on account of friction, so here it is impossible to design any circuit with no losses in it.

The energy originally stored in the condenser ($\frac{1}{2}$ $CV^2$ joules) will be gradually dissipated in the following "Damping Losses":—

(1) Energy expended in producing heat with accompanying light and noise at the spark gap, *i.e.*, $I^2$ R losses in the spark gap, and conductors.

(2) Hysteresis losses in the condenser.

(3) Energy expended by currents induced in neighbouring conductors.

**298. The Train of Waves.**—The combined effect of these damping losses will result in the condenser being charged to a slightly lower voltage at each successive half cycle, until eventually the process stops when the energy available is insufficient to maintain the heat of the spark gap.

If the spark gap were to maintain its insulation resistance at the same high value as when it was broken down by the first charge put into the condenser, then succeeding charges, of less voltage, could not force any current across it after the first half cycle.

It so happens, however, that after the first spark, the resistance of the gap falls off enormously, owing to the air between the plugs becoming "ionised" and to vapourisation of the copper plugs. The resistance of the gap falls from several hundred thousand ohms to a few hundredths of an ohm, and therefore succeeding half cycles are able to follow one another.

This action may be represented diagrammatically as in Fig. 155.

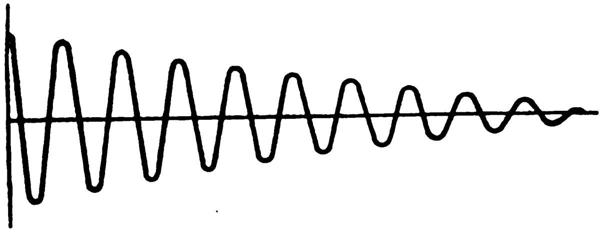


FIG. 155.

Fig. 155 represents the voltage to which the condenser C is charged at each successive half cycle, the vertical ordinates representing voltages across the condenser.

In the same way, the current flowing in the circuit may be represented by a similar diagram (Fig. 156),

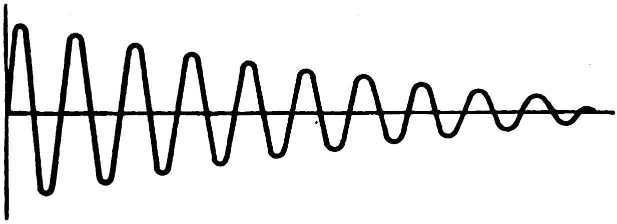


FIG. 156.

observing that when the condenser is fully charged, no current is flowing in the circuit, and when the current has risen to its maximum value, the condenser is not charged at all.

This succession of cycles of E.M.F. or current, representing what occurs when a condenser expends a certain charge put into it in the manner described above, is termed a **"Train of Waves."**

**299. Natural Frequency of Discharge.**—We have already learnt, Chapter V., para. **233**, that the **natural frequency** of any circuit comprising inductance and capacity, whose resistance is small, is given by the formula—

frequency $f = \frac{1}{2\pi\sqrt{LC}}$ where "L" is measured in henries and "C" in farads. (1)

or that $f = \frac{3 \times 10^7}{2\pi\sqrt{LC}}$ where "L" is measured in microhenries and "C" in jars. (2)

So, also, when a condenser discharges freely across a spark gap through an inductance, the oscillation will take place at the **natural frequency** of the circuit, as given by the above formula.

This means that if a train of waves were to last for one complete second it would contain " f " complete cycles of voltage or current.

**Example 42.**

Find the frequency of discharge of a circuit composed of a condenser of 50 jars and an inductance of 2 mics :—

$$f = \frac{3 \times 10^7}{2\pi\sqrt{50 \times 2}} = \frac{3 \times 10^6}{2\pi} = 4{\cdot}776 \times 10^5 = 477{,}600 \text{ cycles per sec.}$$

The oscillation will not last for anything like this number of cycles, and will be damped out in anything between 10 and 200 cycles (according to the losses in the circuit), but it occurs at this **rate.**

**300. Oscillation Constant.**—From formula (1) it will be seen that the frequency of the oscillations varies inversely with the square root of the product of the inductance and capacity or " LC " value.

For this reason the LC value of a circuit is known as its "**Oscillation Constant.**"

**301. Period.**—If the circuit oscillates at the rate of " f " cycles per second, then one cycle will last for a period of $\frac{1}{f}$ of a second.

$$\text{Period} = \frac{1}{\dfrac{3 \times 10^7}{2\pi\sqrt{LC}}} = \frac{2\pi\sqrt{LC}}{3 \times 10^7} \text{ seconds.}$$

The duration of a cycle in seconds is termed the " Natural Period " of the circuit.

**Example 43.**

Find the natural period of the circuit given in **Example 41**:

$$\text{Period} = \frac{2\pi\sqrt{50 \times 2}}{3 \times 10^7} = \frac{2\pi}{3 \times 10^6} = 2{\cdot}1 \times 10^{-6} \text{ seconds.}$$

$$= 2{\cdot}1 \text{ micro-seconds.}$$

**302. Wave-Length.**—The high frequency oscillation discussed above will produce a high frequency disturbance in the æther in the neighbourhood of the circuit.

Now, it is a well-established fact that all disturbances of the æther travel at the same rate, viz., **$3 \times 10^8$ metres per second** (*see* para. 13).

It has been explained in Chapter I., para. 10, that the wave-length ($\lambda$) of a wave in any medium is equal to its speed of travel (v) divided by its frequency (f): *i.e.*, $\lambda = \frac{v}{f}$.

In the case of the æther wave therefore, λ in metres $= \dfrac{3 \times 10^8}{f}$

$$= 3 \times 10^8 \div \frac{3 \times 10^7}{2\pi\sqrt{LC}} = 20\pi\sqrt{LC} \quad \left.\begin{array}{l}\lambda \text{ in metres.}\\ L \text{ in mics.}\\ C \text{ in jars.}\end{array}\right.$$

$$= 62{\cdot}8\sqrt{LC}$$

(In units of microhenries and microfarads

$$\lambda = 600\pi\sqrt{LC} = 1885\sqrt{LC}).$$

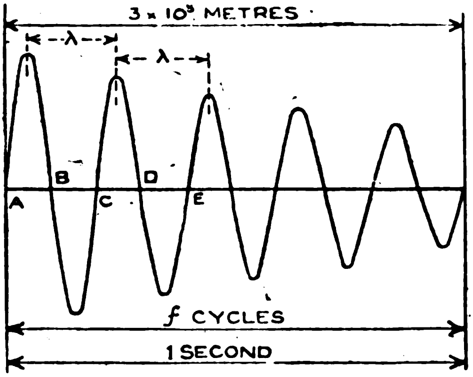


Fig. 157.

Three methods are used in the Service to describe a wireless wave. A wave may be described by—

(*a*) Its **oscillation constant,** or **LC value.** This is inconvenient for commercial or inter-Service use, on account of the various units used for capacity.

(*b*) **Its frequency,** measured in **kilocycles** or thousands of cycles. This method is being widely adopted, as it is convenient for determining readily the allocation of waves for different services so that they will not interfere with one another.

(*c*) **Its wave-length,** as determined above.

**303.** The formulae given in paras. **299** and **302** are of constant use in the study of W/T. They may be arranged in several ways :—

(*a*) To find frequency in kilocycles from LC value :—

$$f = \frac{3 \times 10^4}{2\pi\sqrt{LC}}.$$

(*b*) To find frequency in kilocycles from wave-length :—

$$f = \frac{3 \times 10^5}{\lambda}$$

(*c*) To find wave-length in metres from LC value :—

$$\lambda = 62{\cdot}8\sqrt{LC}.$$

(*d*) To find wave-length from frequency in kilocycles :—

$$\lambda = \frac{3 \times 10^5}{f}.$$

(*e*) To find LC value from frequency in kilocycles :—

$$LC = \left(\frac{3 \times 10^4}{2\pi f}\right)^2.$$

(*f*) To find LC value from wave-length :—

$$LC = \left(\frac{\lambda}{62 \cdot 8}\right)^2$$

**304. The Closed Oscillator.**—The oscillator we have described so far is what is known as a "Closed Oscillator." The condenser is an artificial one, of large capacity, so that it need not be charged up to an excessive voltage V to get a given charge of Q coulombs into it,

$$\left(V = \frac{Q}{C}\right).$$

The inductance is compact in form, of a value of only a few microhenries, and is designed to have as small a resistance as possible to the high frequency currents passing through it.

With such a circuit, two fields, one electric and one magnetic, are set up. Both these fields are of an oscillatory nature, passing through cycles of positive and negative values.

**The Magnetic Field** surrounds the wires, and, more particularly, passes through the turns of the inductance. Theoretically, the magnetic field extends to an infinite distance; practically, however, it falls off to a negligibly small value at a distance of a few **feet** from the oscillator.

**The Electric Field** is established between the plates of the condenser. Theoretically, again, this field extends to an infinite distance: but practically, if the plates are close together, it falls to a negligible value at a distance of a few **inches** from the edges of the plates.

It thus follows that the only space near the closed oscillator which is called upon to bear both a magnetic and an electric field, is that space between the plates of the condenser.

Thus, a negligibly small amount of energy is radiated away from the closed oscillatory circuit in the form of **electro-magnetic waves.**

As our entire object is to radiate away energy in this form, something else is necessary.

**305. The Open Oscillator.**—Let us gradually separate the plates of the condenser. Then, as the plates separate, a greater and greater volume of the surrounding space is carrying **both** the fields. Energy will be radiated away in the form of true waves which are self-supporting and spread out to great distances from the oscillator. This point is dealt with in Chapter XV.

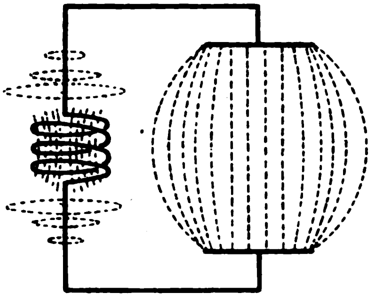


FIG. 158.

Such a condenser is provided, in effect, by the **aerial** (or "antenna").

**306. The Aerial Circuit.**—Theory and experience have shown that the most efficient form of aerial is the well-known "Roof" type, as generally fitted in ships (Fig. 159 (*a*)). The bottom of the aerial is connected, generally, to the earth or surface of the sea. The earth forms one plate of a condenser, the overhead wires the other plate.

The dielectric consists of the intervening layer of air.

(An aerial is conventionally represented as in Fig. 159 (*b*).)

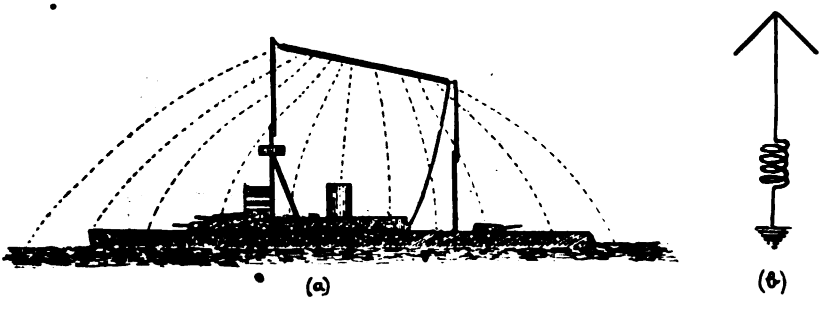


FIG. 159.

**307. Natural Capacity of an Aerial.**—The higher we make the overhead, or "roof" part of our aerial, the better it radiates energy.

Since the capacity of a condenser varies inversely with the thickness of the dielectric—in this case the distance between the aerial and earth—the capacity of the aerial will be small.

Again, the capacity varies directly as the area of dielectric charged, that is, of the opposed plates.

The earth is big, but the overhead portion of an aerial is very limited, especially in a ship. Consequently this factor also goes to keep the condenser capacity small.

We therefore expect to find the capacity of our aerial a small figure, and in practice it varies from about 0·3 jar in a submarine to about 2 jars in a big ship. (Shore station aerials may have larger capacities than these.)

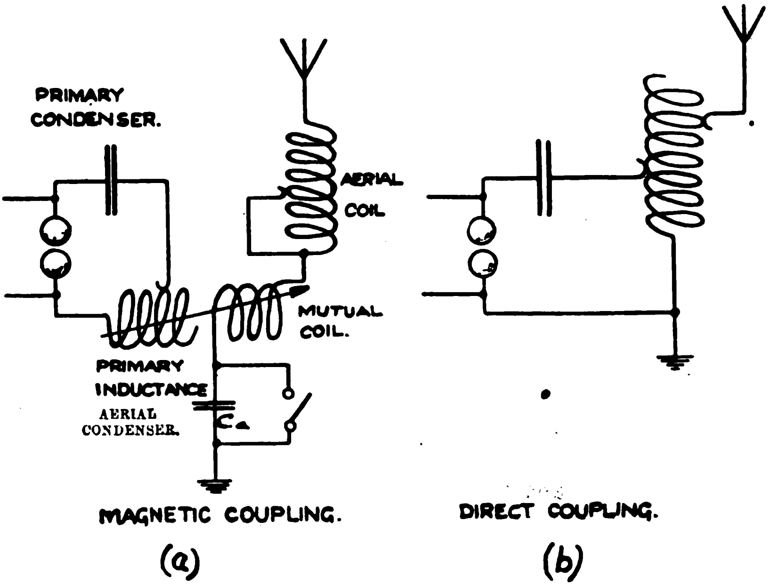
The natural capacity of an aerial is denoted in the Service by the letter "$\sigma$" (sigma) to distinguish it from other capacities.

**308. Natural Inductance of an Aerial.**—An aerial will likewise have a certain natural inductance, made up of the inductance of the wires composing the "roof," and of the "feeders" (or wires from the W/T office to the roof).

As these wires are in parallel with one another, their total inductance will not be very great, and generally lies between 10 and 70 mics. for ship aerials.

**309. Primary and Aerial Circuits.**—We have seen that our oscillation is generated in a closed oscillator, generally termed the primary circuit. Also, that, in order to create an electromagnetic disturbance in the æther, it must be transferred to the aerial circuit.

This may be done in one of two ways, illustrated in Fig. 160 (*a*) and (*b*). These two methods are known as "Magnetic" and "Direct" coupling.



MAGNETIC COUPLING. (a)

DIRECT COUPLING. (b)

Fig. 160.

**310. Magnetic Coupling,** Fig. 160 (*a*).—Here a coil of wire (known as the "Mutual Coil") in series with the aerial, is placed close to the primary inductance.

As the lines of magnetic force rise and fall round the primary inductance, they also cut the mutual coil and induce an oscillatory E.M.F. across it, which will tend to set up an oscillatory current in the aerial.

**311. Direct Coupling,** Fig. 160 (*b*).—Here a small portion of inductance is common to both circuits, with the same result—that an oscillatory E.M.F. is produced across a portion of the aerial circuit by the oscillatory discharge of the primary condenser. It should be noted that the circuit is that of the auto-transformer.

**312. Resonance between Primary and Aerial Circuits.**—We have already seen that the primary circuit has a certain natural frequency of its own, depending on its capacity and inductance.

Similarly, the aerial circuit will have a certain natural frequency of its own at which it will oscillate most readily.

This natural frequency will be equal to $\frac{3 \times 10^7}{2\pi \sqrt{LC}}$, where LC, is the natural inductance ($L_{ae}$) of the aerial multiplied by its natural capacity ($\sigma$).

NOTE.—The wave-length whose LC value is the same as the $L_{ae}\,\sigma$ value of the aerial is termed the "Fundamental Wave-length," and may be denoted by $\lambda_n$.

Having adjusted the primary circuit to the LC value which will give the wave required, we must next adjust the aerial circuit to the same LC value: then the two circuits will be in resonance, and we shall not only get the maximum current in the aerial circuit, but also the required wave radiated by the aerial.

For all waves other than the fundamental we must either increase or decrease the LC value of the aerial circuit.

In practice, the LC value of an aerial is generally increased by adding inductance in series, and decreased by adding capacity in series, as in Fig. 160 (*a*).

**313. Increasing the Wave-length.**—The inductance which is always in circuit is that of the aerial itself ($L_{ae}$) and that of the mutual coil ($L_m$).

The coil used for additional inductance is termed the "Aerial Coil" or "Aerial Tuning Inductance" (Fig. 160).

**Example 44.**

It is required to find how much inductance must be added on the aerial coil to tune to a wave of 2000 metres, in a circuit where $L_{ae} = 30$ mics, $L_m = 10$ mics, and $\sigma = 1 \cdot 2$ jars.

The required LC value $= \left(\frac{\lambda}{62 \cdot 8}\right)^2 = \left(\frac{2000}{62 \cdot 8}\right)^2 = 1013$ mic-jars (*see* App. D., Table I).

Total inductance required $= \frac{LC}{\sigma} = \frac{1014}{1 \cdot 2} = 845$ mics.

Inductance already in circuit $= 30 + 10 = 40$ mics.

Therefore inductance required on aerial coil $= 845 - 40 = 805$ mics.

**314. Decreasing the Wave-length below the Fundamental.**—If we join a condenser (Ca) in series with the aerial, as in Fig. 160, this acts in series with the aerial capacity, and so reduces the total capacity of the circuit.

**Example 45.**

It is required to tune the aerial circuit given in example 44 to a wave of 250 metres.

$$\text{LC} = \left(\frac{250}{62\cdot8}\right)^2 = 15\cdot8 \text{ mic-jars.}$$

Total inductance already in circuit = 40 mics.

$$\text{Therefore total capacity required} = \frac{15\cdot8}{40} = 0\cdot375 \text{ jars.}$$

As a rule the aerial condenser is not adjustable.

Let us try a condenser of 0·5 jar in series.

This, in series with the aerial capacity, will give a total capacity as follows :—

$$\frac{\sigma \times \text{Ca}}{\sigma + \text{Ca}} = \frac{1\cdot2 \times \cdot5}{1\cdot2 + \cdot5} = \frac{\cdot6}{1\cdot7} = 0\cdot33 \text{ jar.}$$

The total capacity has thus been reduced a little too low, and we must add some inductance to get exactly in tune.

$$\text{Total inductance required} = \frac{\text{LC}}{\text{C}} = \frac{15\cdot8}{0\cdot33} = 45 \text{ mics.}$$

We already have 40 mics in circuit.

Therefore 5 mics must be added on the aerial coil to get in resonance.

**To sum up** : in order to transmit a wave of a certain length, we first adjust the primary circuit to the LC value which gives this wave, and then tune the aerial circuit to the same LC value as that to which the primary is tuned.

The actual method of making this tuning adjustment is described in Chapter XIX.

**315. The Plain Aerial System.**—As a matter of historical interest, the "**Plain Aerial**" system of transmission may be here described.

When wireless telegraphy was first developed, the coupled circuit system of transmission was not used. The spark gap was joined directly in series with the aerial, with the source of high voltage supply across it.

The capacity charged up to discharging voltage was thus the capacity of the aerial itself.

The result of this arrangement was a very heavily damped wave, as any circuit such as this, of small capacity and big inductance with the high resistance of a spark gap in series with it, does not make a persistent oscillator.

The resulting wave train was of the nature shown in Fig. 161, *i.e.*, one which started with a big initial voltage, but which was damped out very quickly.

A wave of this nature was very objectionable, because it interfered considerably with all receiving aerials in the neighbourhood, whether tuned to it or not, and—as will be understood after reading Chapter X.—made selective working in a fleet impossible.

A second objection to the system is that since the charging mains are directly connected to the aerial, a very bad shock would be taken from the latter by anyone touching it, and, further, unless the insulation of the aerial is good, no spark can be obtained.

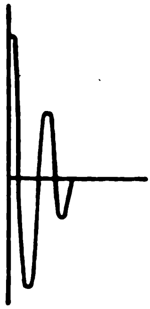


FIG. 161.

**316. Tight and Loose Coupling.**—It was stated in para. 309 that the oscillation set up in the primary circuit is transferred to the aerial circuit by magnetic induction between the primary and mutual coils.

Since our object is to induce the maximum energy possible into the aerial, it might appear at first sight that the closer the mutual coil is to the primary the better.

That is not so, for the following reasons :—

Consider the primary circuit steadily oscillating; each time the magnetic field rises and falls round the primary inductance a certain amount of energy is transferred to the aerial *via* the mutual coil, until eventually all the energy originally available in the primary circuit has been transferred to the aerial circuit.

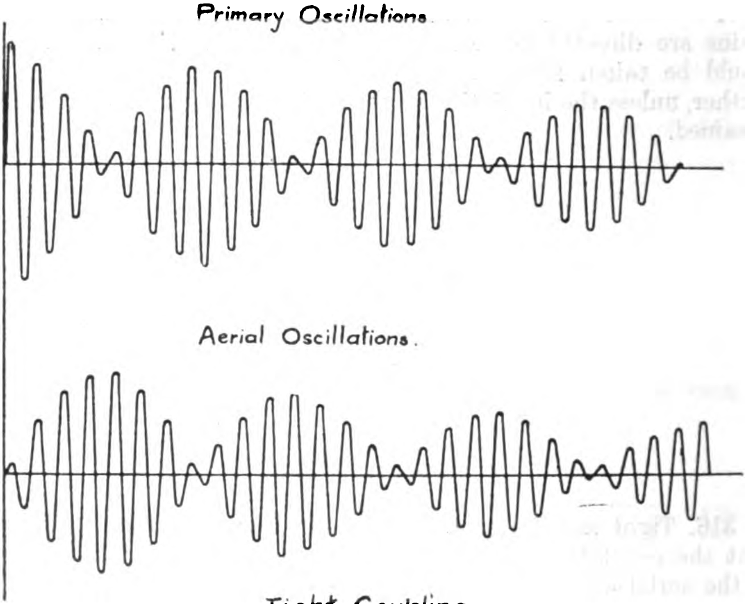
Similarly, when the aerial circuit is oscillating, it will gradually transfer its energy back to the primary, until eventually all the energy has been handed back to the primary circuit, ignoring $I^2R$ losses and the amount radiated.

This transfer and re-transfer of energy between primary and aerial continues until all the energy originally available has been expended in overcoming various losses, which will be detailed later.

Every time the primary is set in oscillation, a great deal of energy will be expended in damping losses in the spark gap, while in the aerial the chief expenditure of energy is by radiation : the latter expenditure is very desirable, but the former is not.

**317. Tight Coupling.**—If the mutual coil is placed close up to the primary, the energy is transferred very rapidly backwards and forwards.

This is known as "Tight Coupling." The effect will be as follows :—

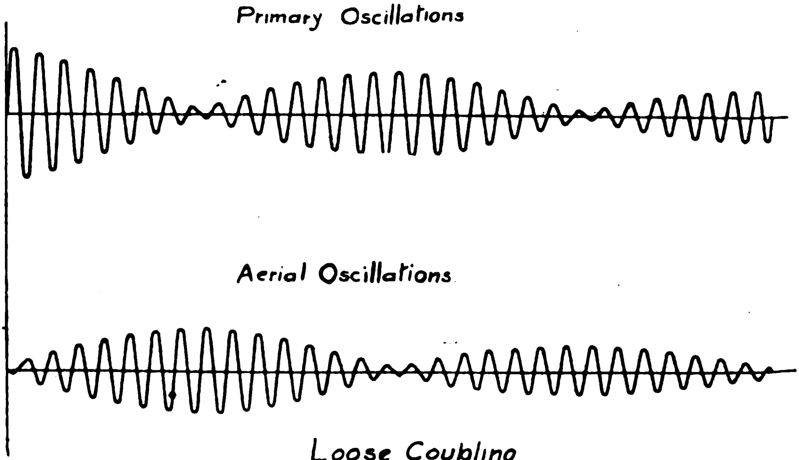


Tight Coupling.

FIG. 162.

It will be seen from the above that the oscillations in both primary and aerial die away and rise again several times in a series of "beats" before the wave train is entirely damped out.

Each time the oscillations are transferred to the primary the evil effect of the spark gap is felt, with consequent loss of energy, which might otherwise have been available for radiation into space.



Loose Coupling.

FIG. 163.

**318. Loose Coupling.**—If the mutual coil be moved further away from the primary the energy will be transferred more slowly between the two circuits, as in Fig. 163, and therefore the primary will not be set in oscillation so often before the wave train finally dies away.

With a tight coupling, then, the voltage in the aerial builds up quickly to a very big value; this has two harmful effects, namely, shock and " brushing."

It was mentioned when speaking of the plain aerial system that this was very undesirable, as the high voltage at the beginning of the wave train interfered with neighbouring aerials, whether tuned to the wave emitted or not.

In the same way, with a tight coupling, a wave is emitted whose peak voltages are high; consequently the aerials of neighbouring ships are set in oscillation, even though they are not tuned to the wave transmitted.

**319. Brushing or " Corona Discharge."**—If the aerial voltage is excessive the insulation of the air between the aerial and neighbouring earthed conductors breaks down, and a violet-blue discharge occurs. This represents a waste of energy, and also discloses the position of the ship at night.

Hence, for these two reasons, the use of tight couplings is undesirable, and should be avoided if possible.

**320. Radiation of Two Waves.**—It has already been shown in Chapter V., para. **271** that if two circuits are coupled together, and if one circuit is energised and the combination allowed to oscillate freely, then the two circuits will not oscillate at a single frequency. Each circuit will apparently have two LC values, viz., $LC\,(1 + k)$ and $LC\,(1 - k)$, where $k = \frac{M}{\sqrt{L_1 L_2}}$ (M being the mutual inductance between the two circuits, and $L_1$, $L_2$, the total inductance in primary and aerial circuits respectively).

These two LC values will correspond to two waves, $\lambda' = \lambda\sqrt{1 + k}$ and $\lambda'' = \lambda\sqrt{1 - k}$, where $\lambda$ is the wave to which each circuit has been separately tuned.

Thus the aerial will radiate two waves, whose difference will depend on the degree of coupling k, between the two circuits.

**321.** The coupling may also be expressed as a percentage.

$$\text{Percentage coupling} = k \times 100.$$

**Example 46.**

**In a spark transmitting circuit tuned to 600 metres, the primary condenser is 40 jars, the aerial capacity is 1·5 jars, and the mutual inductance between primary and aerial circuits is 2 mics. Find the two waves radiated, and the percentage coupling.**

The LC value of each circuit will be

$$\left(\frac{600}{62 \cdot 8}\right)^2 = 91 \cdot 2 \text{ mic-jars.}$$

$$L_1 = \frac{91 \cdot 2}{40} = 2 \cdot 28 \text{ mics} : \quad L_2 = \frac{91 \cdot 2}{1 \cdot 5} = 60 \cdot 8 \text{ mics.}$$

$$k = \frac{M}{\sqrt{L_1 L_2}} = \frac{2}{\sqrt{2 \cdot 28 \times 60 \cdot 8}} = \cdot 17.$$

$$\lambda' = \lambda \sqrt{1 + k} = 600 \sqrt{1 + \cdot 17} = 600 \times 1 \cdot 081 = 649 \cdot 6 \text{ metres.}$$

$$\lambda'' = \lambda \sqrt{1 - k} = 600 \sqrt{1 - \cdot 17} = 600 \times \cdot 9109 = 546 \cdot 5 \text{ metres.}$$

The percentage coupling $= k \times 100 = 17\%$.

**322.** We seem here to have two conflicting statements. We say in paras. **316** and **317** that the energy in the aerial is in the form of "beats," as shown in Fig. 162 and 163, and we say in para. **320** that two waves, differing in frequency, are set up in the aerial.

The truth of both these statements can be reconciled by drawing these two waves occurring simultaneously.

In Fig. 164 curve A shows f″, the higher frequency set up in the aerial, and curve B shows f′, the lower frequency.

As these frequencies are different, it follows that if they start in step they will work out of step, then in step, then out of step and so on, just as two men walking side by side and taking a different length of stride, get in and out of step in turn.

When the two waves are in step, it means that the currents due to the two waves are flowing in the same direction, and when out of step, in opposite directions.

The **total** current at any moment can be found by adding the height of these curves together at each moment.

The result is shown in Curve C, which corresponds with the lower curve of Fig. 162.

From this we see that the current in the aerial rises and falls in a series of beats, being a maximum when the waves are exactly in phase, and a minimum when the two waves are exactly out of phase. Similarly, the instantaneous voltage in the aerial can be found by drawing two voltage curves for the two frequencies and adding them together.

Hence the total voltage and current in the aerial does rise and fall in a series of beats, and these beats are due to the two waves oscillating simultaneously at the two different frequencies, f′ and f″.

**323. Drawback of Radiating Two Waves.**—In designing wireless circuits, we have two objects always before us :—

(*a*) To radiate as much energy as is required on the wave we wish to transmit.

(*b*) To radiate as little energy as possible on any other wave.

If this second object is fulfilled, then communication from a fleet to a number of shore stations or outlying ships is possible with a minimum amount of interference.

For example, the ideal condition is illustrated in Fig. 165.

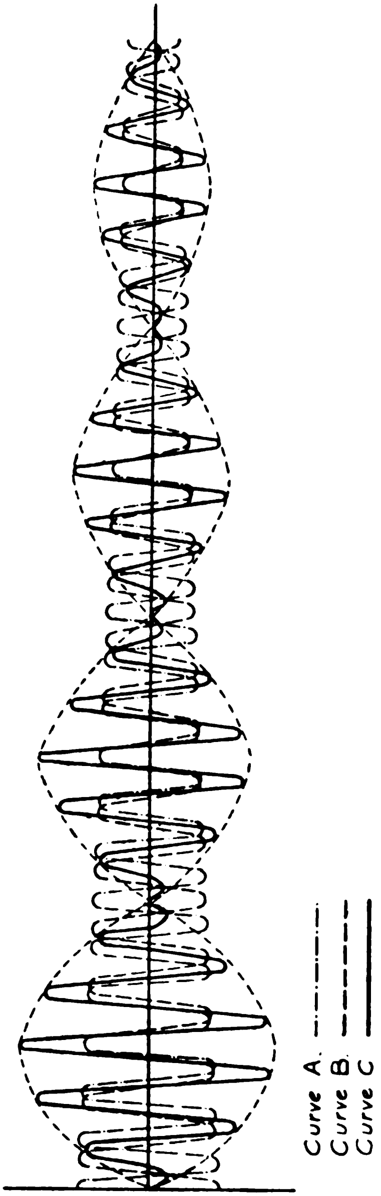


FIG. 164.

Fig. 165 shows that the transmitting ship, tuned to 600 metres, radiates a maximum amount of energy on this wave,

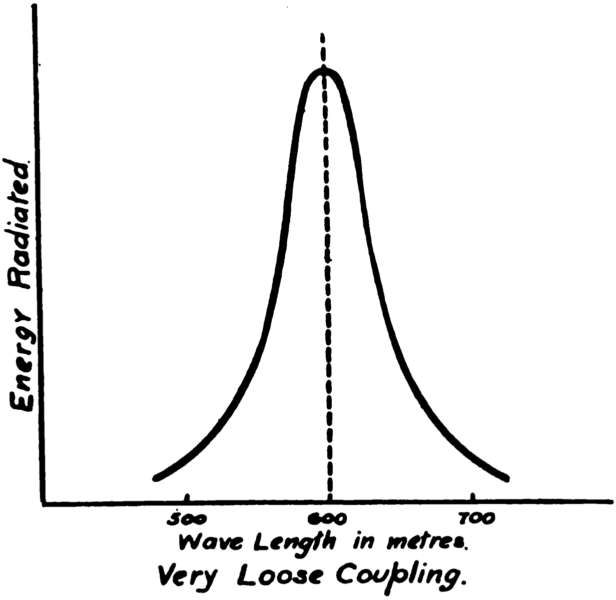


FIG. 165.

but radiates practically none on 500 and 700 metres, and therefore does not interfere with other ships trying to communicate on these waves.

But, if instead of radiating only the wave to which our primary and aerial are separately tuned, we radiate our energy in two waves widely separated from one another, we shall interfere seriously with other lines of communication.

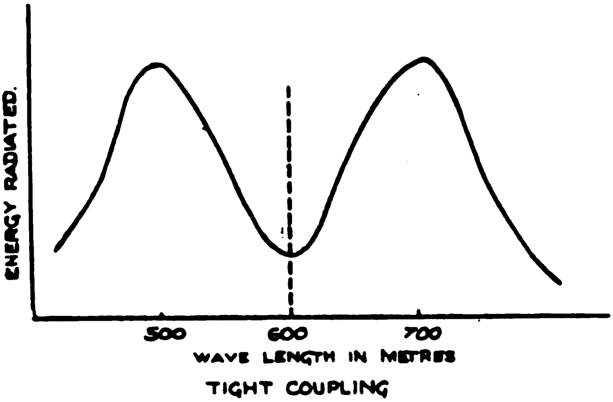


FIG. 166.

For example, if our correct wave is 600 metres, and if owing to the tightness of our coupling we radiate two waves, the long one being 700 metres and the short one 500 metres (a result which would be given by a 33 per cent. coupling), then we shall get a curve of energy radiated as in Fig. 166, which will give bad interference on 500 and 700 metre waves.

This is then another reason why the use of a tight coupling should be avoided.

**324. Factors affecting Coupling.**—We saw from para. **320** that the greater the coupling factor "k" the tighter is the coupling, and the further apart are the two resultant waves.

Let us consider the expression $k = \frac{M}{\sqrt{L_1 L_2}}$ and see how it affects our oscillatory circuits.

"M" is a measure of the mutual inductance between primary and aerial circuits; this depends on two factors :—

(*a*) How close the mutual coil is to the primary coil.
(*b*) How many turns of mutual coil are used.

From the expression $\sqrt{L_1 L_2}$, which is a measure of the amount of inductance used in the primary and aerial circuits to tune up to any particular wave, we learn that, with a given primary and aerial capacity, **the longer the wave the looser the coupling** for any given adjustment of the mutual coil.

Also, that if two ships, one with an aerial of large capacity and one with an aerial of small capacity, are both transmitting on the same wave and using the same value of "M," then the one with the largest aerial capacity will have the tightest coupling, for she will have the least "$L_2$" added to tune to that wave.

**Example 47.**

Two ships—"A" and "B"—both have their primary and aerial circuits tuned to 500 LC. Each has a primary condenser of 50 jars and a mutual inductance M, between primary and aerial circuits, of 10 mics. The aerial capacity of ship A is 2 jars, and that of ship B is 1·2 jars. Find the percentage coupling in each case.

In each case $L_1 = \frac{500}{C_1} = \frac{500}{50} = 10$ mics.

**Ship A.**—

$$L_2 = \frac{500}{2} = 250 \text{ mics.}$$

$$k = \frac{M}{\sqrt{L_1 L_2}} = \frac{10}{\sqrt{10 \times 250}} = \frac{10}{50} = \cdot 2 = 20\% \text{ coupling.}$$

**Ship B.**—

$$L_2 = \frac{500}{1 \cdot 2} = 416 \cdot 6 \text{ mics.}$$

$$k = \frac{10}{\sqrt{10 \times 416 \cdot 6}} = \frac{10}{64 \cdot 5} = \cdot 155 = 15 \cdot 5\% \text{ coupling.}$$

**325. To sum up,** we may say that—

Tight coupling results in a wave that starts with a big initial amplitude, but is quickly damped out. A double frequency effect is produced, which interferes considerably with lines of communication on other waves.

As the coupling is loosened, the energy is transferred more gradually between primary and aerial, resulting in the aerial being charged up to a lower voltage each time. Neighbouring ships on other wave-lengths will not be interfered with so much, and brushing losses will be reduced.

The double frequency effect will become less and less marked, and the two waves will gradually merge into one another, until their difference (which always exists) is inappreciable.

The question of which coupling produces the biggest currents in a receiving aerial depends on the design of the receiving circuits and detector (*see* para. 433).

**326. Damping and Persistency.**—We have already seen that the oscillatory discharge of a condenser across a spark gap results in a wave whose energy is continually decreasing, and that the successive half cycles of voltage or current may be represented as follows :—

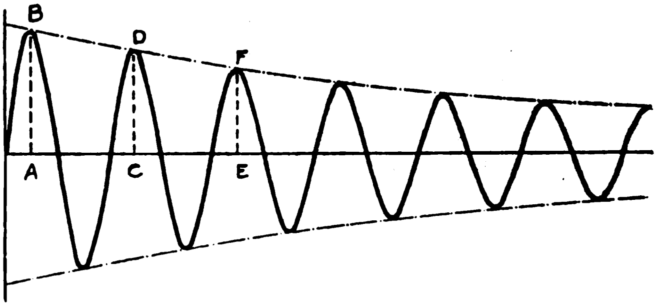


Fig. 167.

Due to a variety of causes, summed up under the general heading "Damping Losses," the successive half cycles of the wave train become less and less, until eventually the wave train dies away completely.

The amplitudes of the successive waves shown in Fig. 167 are the height AB, CD, EF, &c.

The heavier the damping losses in the primary and aerial circuit, the less persistent is the wave said to be.

The "Persistency" of a wave is the ratio of the amplitude of any half-cycle to that of its immediate predecessor in the same direction : it may be expressed as a percentage. Thus, in Fig. 167, if the persistency were 80 per cent., we should have

CD = 80 per cent. or ·8 of AB ;
EF = 80 per cent. or ·8 of CD, &c.

The amplitudes would thus decrease in "geometrical progression," *i.e.*, any amplitude is obtained from the one preceding it by multiplying it by the constant multiplier 0·8.

**327.** The damping is usually expressed by the "Logarithmic Decrement" (log. dec. or $\delta$) which is the Napierian Logarithm of the ratio of any amplitude to its immediate successor in the same direction.

NOTE.—Common Logs. are obtained from the base 10, and Napierian (or Natural) Logs. from the base 2·71828 ($e$). To obtain Napierian Logs. from Common Logs. multiply by 2·3026.)

Thus, in the example given above, instead of talking about a "persistency" of ·8 or 80 per cent., we should say the "log. dec." is

$$\text{the Napierian Log. of } \frac{100}{80}$$

$$= \left(\text{the Common Log of } \frac{100}{80}\right) \times 2\cdot3026$$

$$= \log_{10} 1\cdot25 \times 2\cdot3026 = \cdot0969 \times 2\cdot3026 = \cdot223.$$

**328. Number of Oscillations.**—Although, in theory, the oscillations would never become absolutely zero, they actually become negligible after a certain time.

If we arbitrarily choose to find the number of oscillations which will be completed before the maximum of current will fall below 1 per cent. of the initial value, we have simply to divide the Napierian log. of 100 by the decrement.

The Napierian log. of 100 is approximately 4·605. The number of oscillations (N) is thus 4·605 divided by the decrement: *i.e.* :—

$$N = \frac{4\cdot605}{\delta}.$$

**Example 48.**

If a wave train has 40 effective cycles in it, find its log. dec.

$$40 = \frac{4\cdot605}{\delta}. \quad \text{Therefore } 40\,\delta = 4\cdot605$$

$$\delta = \frac{4\cdot605}{40} = 0\cdot1151.$$

**329.** This damping decrement is due to certain losses, the most important of which are :—

(*a*) Damping due to ohmic resistance. This includes the ohmic resistance losses in primary and aerial conductors, and the losses in the spark gap.

(*b*) Damping due to eddy currents induced in neighbouring conductors.

(*c*) Damping due to leakage through faulty insulation resistance.

(*d*) Damping due to energy radiated away into the surrounding æther.

We will examine these losses separately (*see also* Ch. XVI.).

**330. Skin Effect.**—Naturally, the greater the resistance of the conductors in the primary and aerial circuits through which the oscillatory currents have to flow, the more quickly will the wave be damped out.

We have to take into account here a peculiar property that high frequency currents have of wanting to flow only on the surface of any conductor; this is termed "Skin Effect."

In any conductor carrying a high frequency current, eddy currents will be induced which tend to neutralise any of the flux cutting the conductor itself. As a result, in a cylindrical conductor all the current tends to flow on the outer surface layers, and none in the centre of the conductor, whereas a direct current takes advantage of the whole cross sectional area of the conductor.

Similarly, in a flat conductor, the current is concentrated on the outer edges.

As a consequence, the resistance of any conductor to high frequency currents is much greater than its resistance to low frequency or direct currents.

The high frequency resistance of a conductor is greater than its resistance to steady or low frequency circuits by an amount depending on the frequency of the current flowing, the diameter of the conductor, and its conductivity.

For example, a copper rod ·59 inches in diameter has a resistance for currents of a frequency of a million, which is about 51 times its steady current resistance.

Hence in all high frequency circuits it is of the utmost importance to provide conductors having the greatest possible surface area for the high frequency currents to flow on, if the damping of the circuit is not to be excessive.

**331. Damping due to Ohmic Resistance.**—The log. dec. per period of a circuit of high frequency resistance R′ ohms, frequency $f$, inductance L henries and capacity C farads, is

$$\delta = \frac{R'}{2fL} = \pi R' \sqrt{\frac{C}{L}}.$$

If L be measured in mics, and C in jars, this becomes

$$\delta = \frac{R'}{9 \cdot 6}\sqrt{\frac{C}{L}}.$$

From this we see that if any circuit of inductance and capacity is set in oscillation, the greater its high frequency resistance, the greater its capacity and the smaller its inductance, the greater will be the damping losses in that resistance.

This is only what we should expect, for we know that the circulating currents at a given E.M.F. are larger in any circuit of large capacity and small inductance than in a circuit of the same LC value, where the capacity is small and the inductance is large.

Hence the $I^2R$ losses in the resistance are large.

In the primary, the resistance of the spark itself is a very big one and cannot be avoided; hence the spark system of generating high frequency oscillations is an inefficient one.

**332. Damping due to Leakage through faulty Insulation.**—If the insulation of the primary and aerial circuits is perfect, no energy is lost from this cause.

But if the spark-gap insulators are dirty, or the deck insulator, aerial outhaul insulators, &c., are covered with oil, soot, or are perished, then a lot of current is wasted in flowing to earth through these high resistance paths, instead of oscillating through the primary and aerial circuits.

In a big ship, these losses can be kept down to very small values by the operator in charge, and the insulation of primary and aerial should always balance at nearly infinity on a bridge megger, but in a submarine the deck insulator may be covered with salt, or may be " washing over," and loss is very difficult to avoid.

The formula giving the loss from these causes is as follows :—

The log. dec. per period of a circuit, whose insulation resistance is R ohms (R should usually be several million), is given by—

$$\delta = \frac{94}{R}\sqrt{\frac{L}{C}} \text{ where } \begin{cases} L = \text{mics,} \\ C = \text{jars.} \end{cases}$$

That is to say, the lower the insulation resistance, the bigger the inductance, and the smaller the capacity the heavier the damping from these causes.

This, again, is only what we expect, for we know that in a circuit where the inductance is big and the condenser is small, the voltages across the inductance and the condenser are big values, hence the voltages applied to the points of poor insulation are big, and the leakage currents to earth are big.

Hence it is specially important to maintain very high insulation in the aerial circuit.

**333. Damping due to Energy Radiated.**—At each cycle of voltage or current in the aerial a certain amount of energy is radiated away into the surrounding æther, and sets up electromagnetic waves, which carry a certain amount of energy to receiving ships or stations.

This also is a damping loss, but it is one that, with certain limitations, we want to be as great as possible.

If it is too great, the wave will be damped so heavily that tuning at the receiving station will not be at all " selective " (*see* Chapter X.).

This damping loss, which is termed the **Radiation Resistance** of the aerial, is almost impossible to calculate, since it depends on the shape and arrangement of the aerial as well as on its height and capacity.

It is known that straight vertical wires make quick radiators, umbrella-shaped aerials slow radiators, while the usual "T" or "inverted L" aerial is a mean between these two.

The following formula is fairly true for aerials of similar shape :—

$$\text{Radiation resistance} = 1{,}600\,\frac{h^2}{\lambda^2},$$

where h is the radiation height of the aerial in metres, and "$\lambda$" the length of the wave, also measured in metres (*see* para. 557).

From this we learn that height is a great advantage; also that an aerial will radiate best at its fundamental wave-length, and that as the wave-length is increased, radiation falls off rapidly.

**334. Effective Resistance of an Aerial.**—It is a very difficult matter to determine these three causes of loss separately.

As, however, they all combine together to damp the wave out, an aerial is often spoken of as having an **effective resistance** of so many ohms.

By this is meant a resistance which would cause the same damping effect as the resistance damping, insulation leakage damping, and radiation damping losses added together.

For example, we saw in Example 48 that a logarithmic decrement of ·118 caused a wave to be damped out in 40 cycles.

If this damping had been entirely due to losses in the aerial, and if the inductance of the aerial circuit were 100 mics, and capacity 1 jar, then this damping could have been caused by an effective resistance of R′ ohms, determined as follows :—

$$\delta = \frac{R'}{9\cdot 6}\sqrt{\frac{C}{L}}.$$

Therefore—

$$R' = \delta \times 9\cdot 6\sqrt{\frac{L}{C}} = \cdot 118 \times 9\cdot 6 \times \sqrt{\frac{100}{1}} = 11\cdot 3 \text{ ohms.}$$

In this case then the effective high frequency resistance of the aerial would be said to be 11·3 ohms.

We shall see later on that, besides suffering from these losses, the wave suffers somewhat while passing through the æther, and also when it arrives in the aerial of the receiving station.

**335. Value of the Primary Oscillating Current.**—It will be useful here to get an idea of the maximum and mean values of the oscillatory current which the primary circuit conductors are called upon to carry.

They may be arrived at as follows :—

It has already been stated (Chapter V., para. **250**) that in a closed oscillating circuit consisting of a condenser of C jars and an inductance of L mics, with a maximum applied pressure of $V_m$ volts, the maximum value of the circulating current at resonant frequency will be—

$$I_m = \frac{V_m}{30}\sqrt{\frac{C}{L}} \text{ ampères,}$$

provided that the resistance of the circuit is low.

Hence, given the values of the inductance and capacity of the circuit, and the voltage to which the condenser is first charged before the insulation of the spark gap breaks down, we may obtain the value of the maximum current which the conductors of the primary circuit will be called upon to carry.

**Example 49.**

Find the maximum current which will flow in a circuit made up of a condenser of 64 jars in series with an inductance of 4 mics, if the condenser is charged up to a discharging voltage of 12,000 volts maximum.

$$I_m = \frac{V_m}{30}\sqrt{\frac{C}{L}} = \frac{12000}{30}\sqrt{\frac{64}{4}} = 400 \times 4 = 1600 \text{ ampères.}$$

**336.** The **average** value of the oscillatory current during the wave train may be found in the following manner:—

The energy stored in a condenser of C farads charged to $V_m$ volts $= \frac{1}{2} C V_m^2$ joules.

So that in the above example the energy originally stored up

$$= \frac{1}{2} \times \frac{64}{9 \times 10^8} \times 12{,}000^2 = \frac{1}{2} \times \frac{64}{9 \times 10^8} \times 144 \times 10^6 =$$

$5 \cdot 12$ joules.

Let us suppose that the damping losses in the primary and aerial circuits may be represented by an effective resistance in the primary circuit of $0 \cdot 7$ ohms, and that due to these losses the oscillation is damped out in the primary after 40 complete cycles.

The natural frequency of the above circuit $= \frac{4 \cdot 8 \times 10^6}{\sqrt{LC}} = \frac{4 \cdot 8 \times 10^6}{\sqrt{4 \times 64}} = 3 \times 10^5$ cycles per second.

One cycle lasts for $\frac{1}{3 \times 10^5}$ seconds, and 40 cycles last for $\frac{40}{3 \times 10^5}$ seconds.

In this space of time $5 \cdot 12$ joules of energy are dissipated.

Therefore in one second $5 \cdot 12 \times \frac{3 \times 10^5}{40}$ joules would be used if energy were dissipated at the same rate for one complete second.

During the discharge, then, the oscillatory circuit does work at the rate of $\frac{5 \cdot 12 \times 3 \times 10^5}{40} = 38{,}400$ joules per second.

But joules per second = watts.

Therefore, when discharging, the oscillating circuit dissipates energy at a rate of 38,400 watts or 38·4 kilowatts, or rather it would do so if the oscillation were to be continuous; but it really only dissipates energy at this rate during the wave train, and then has a rest until the next wave train starts.

This power is expended in certain damping losses, which are equivalent to a total $I^2R$ loss in the effective resistance of 0·7 ohms mentioned above.

Hence $I^2R = 38400$ watts,

$$I^2 = \frac{38400}{\cdot 7},$$

$$I = \sqrt{\frac{38400}{\cdot 7}} = 234 \cdot 3 \text{ ampères.}$$

So that the average value of the oscillating current, starting at 1,600 ampères at the peak of the first half-cycle, and dying away to zero, will be 234 ampères.

This explains why the conductors of primary oscillating circuits have to be made of such a large sectional area.

## CHAPTER VIII.

## THE SPARK TRANSMITTING CIRCUIT COMPLETE.

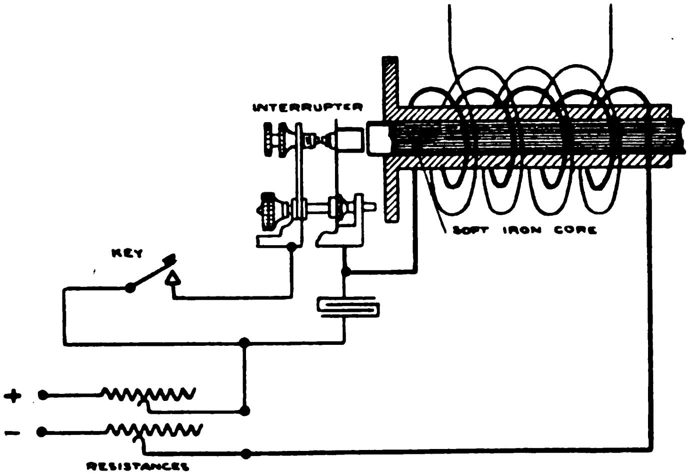
In Chapter VII. we discussed how a condenser, when once charged up to a certain high voltage, was used to produce a high-frequency oscillation in the æther.

We must now discuss carefully the various methods used for charging the condenser up to discharging voltage.

**337. The Induction Coil.—Action and Use of Induction Coils.**—Alternators (or rotary converters) and transformers are now used almost universally for charging condensers of spark transmitters.

Occasionally it happens, however, that it is not convenient to run an alternator, owing to there not being a D.C. supply of high enough voltage or power available, or it may be required to extemporise a small set to work off an existing D.C. supply or a low-voltage accumulator.

In that case, an induction coil forms a very convenient means of converting a direct current into an intermittent current at high voltage.



*Induction Coil.*

FIG. 168.

**338. Construction.**—An induction coil consists of a **primary coil** of thick wire wound with a number of turns on an iron core composed of a bundle of soft iron wires.

The primary coil is enclosed in an ebonite tube. Outside this again is the secondary coil, which consists of some miles of fine copper wire.

It is built up of a number of flat coils or sections, made by winding the wire between paper discs in a spiral form. The coils are joined in series, inner ends and outer ends of coils being joined together alternately, so that the current flows in the same direction in each coil.

By connecting them in this manner, there is no undue potential strain between the end of one section and the end of the next section to which it is joined.

In series with the primary winding is joined the "Interrupter" or "Make and Break."

This consists of a soft iron armature, secured to the top end of a flat steel spring whose tension can be adjusted by means of an ebonite wheel and adjusting screw.

This armature is close to one end of the iron core, the play between the two being about $\frac{1}{16}$-inch.

The armature carries a small platinum contact. Close to the vibrating armature is a fixed standard carrying an adjustable contact, with a platinum tip. These contacts are normally held together by the tension of the spring.

Suitable terminals are provided to which the sending key should be joined.

A condenser of large capacity is joined across the key and interrupter contacts to minimise sparking, &c.

**Two Resistances** are provided which are joined in series with the D.C. supply, in order to limit the voltage to a value suitable for working the coil.

**339. Action.**—When the key is pressed a current flows from the main positive lead, through the key, across the interruptor contacts, through the primary winding, through the resistance, and back to negative.

The core of the coil is magnetised, and the armature is attracted to it. The contacts of the interrupter are therefore suddenly separated and the current through the primary falls to zero very rapidly.

As soon as the primary current has died away the armature will be released by the core and will fly back, and its contact will make connection again with the fixed contact. The primary current will again rise to a maximum, but only slowly, owing to the big self-inductance of the primary coil.

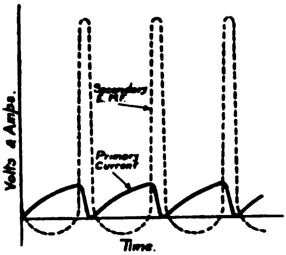
The primary circuit is thus made and broken very rapidly, and the primary current rises slowly at "make" and falls very rapidly at "break."

**340. Secondary Voltage.**—When the primary circuit is broken, the big primary flux will collapse inwards very rapidly, and, cutting the great many turns of the secondary winding, will cause a big momentary E.M.F. between the secondary terminals. This voltage will be greater—

(*a*) the faster the fall of the primary current;

(*b*) the greater the primary current and its attendant flux;

(*c*) the greater the number of secondary turns.



*Primary Current and Secondary Voltage in Induction Coil.*

Fig. 169.

When the primary current is growing again, there will be an induced secondary voltage set up in the opposite direction, but it will only be a small one, since the primary current rises comparatively slowly at " make."

These actions are illustrated in Fig. 169, the thick line showing the slow rise and sudden fall of primary current and the dotted line the small induced secondary E.M.F. when the primary current is rising, and the big secondary E.M.F. when the primary current is falling.

It can thus be seen that every time the interrupter breaks contact a very big momentary E.M.F. is produced between the secondary terminals.

Let us connect the secondary of an induction coil to an oscillatory circuit, consisting of a condenser, an inductance and a spark gap.

When the interruptor breaks the primary circuit, the induced E.M.F. in the secondary charges the condenser to such a high voltage that a spark takes place between the balls.

The high resistance of the gap having now been bridged by a spark, the condenser discharges through the inductance and the spark gap, and a high-frequency oscillating current is set up in the circuit.

This action takes place for each break of the interrupter.

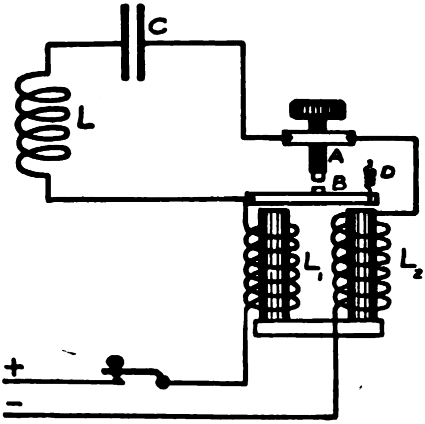
**341. Limitation of an Induction Coil.**—Although an induction coil may produce a momentary voltage of as much as 150,000 volts, yet it is not a very effective means of charging up a condenser for the reason that the **duration** of the high secondary voltage is very short.

The time taken to charge up a condenser of C farads varies as CR, the capacity of the condenser and the resistance through which it is charged.

Since the secondary winding is made up of a great many turns of very fine wire its resistance is high, and consequently the secondary current small; so for charging up a large condenser C through this high resistance the charging voltage ought to be applied for a long time.

Unfortunately, however, the high secondary voltage only lasts for a very short time, consequently an induction coil is only suitable for charging up a comparatively small condenser.

**342. The Use of Buzzers.—The Attracted Armature Type.**— Another method of energising an oscillatory circuit is by means of a buzzer. This is illustrated in Fig. 170.



*Typical Buzzer.*

FIG. 170.

Here we have a fixed contact A, and a contact B carried on an armature which is free to vibrate. A and B are normally held together by a spiral spring D.

Joined to B and A are two coils of high inductance, $L_1$ and $L_2$. This arrangement constitutes the buzzer. A D.C. source of supply is joined to $L_1$ and $L_2$, and is made and broken by a signalling key.

Across the make and break AB is joined a circuit, LC.

**343. Action :—**

(*a*) When the key is pressed current flows through $L_1$, across the contacts AB, and back through $L_2$. The coils $L_1$ and $L_2$ are magnetised and attract the armature B away from A.

(*b*) When the D.C. circuit is suddenly broken at AB, the current cannot suddenly cease owing to the high inductance of the coils $L_1$ and $L_2$, so that the condenser C is charged up by the inductive kick from $L_1$ and $L_2$, the left-hand plate being charged positively and the right-hand one negatively.

The energy that was stored in the magnetic fields round $L_1$ and $L_2$ is transferred to C when the current in $L_1$ and $L_2$ has been reduced to zero.

(*c*) The coils $L_1$ and $L_2$ being demagnetised, the moving contact will fly back towards the fixed contact.

When the two contacts are nearly together again, the P.D. between the condenser plates will cause a spark to pass across the small gap so formed, and the discharge of the condenser C will set up a high frequency oscillation in the circuit formed by the condenser C, the inductance L and the small spark gap between A and B.

(*d*) When A and B touch once more, a direct current will flow through $L_1$ and $L_2$, and the operation will continue.

This action may be summarised as in Fig. 171.

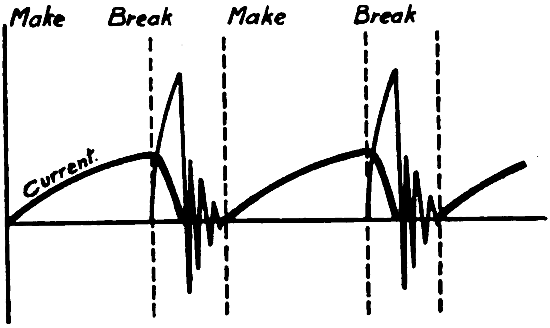


FIG. 171.

The thick line illustrates the slow rise of the direct current through $L_1$ and $L_2$ at the moment of "make," and the sudden fall of the direct current at the moment of "break."

The thin line shows the voltage applied to the condenser C at the moment of "break," and the high frequency oscillation set up in the circuit LC.

**344.** The above method of energising an oscillating circuit is used extensively—

(*a*) to energise a transmitting oscillator, when only a comparatively short range is required;

(*b*) to energise receiving circuits for testing crystals, or for tuning purposes.

**345. A great advantage** of this method of energising a transmitting oscillator is that, with reasonably loose couplings, only one wave is emitted from the aerial, and not the two waves (due to interaction of primary and aerial circuits) as described in para. **320**, because in cases such as this, of a gap of decreasing length, the shorter the gap gets the higher does its high frequency resistance become; also the large mass of metal close to the spark conducts the heat away very rapidly. Consequently, the primary oscillation is quickly damped out, and the oscillation continues in the aerial circuit only, as described in para. **365.**

**346. The Motor Driven Buzzer.—A motor buzzer** is a more efficient method of energising an oscillating circuit than the attracted armature type of buzzer.

It may be represented diagrammatically as follows :—

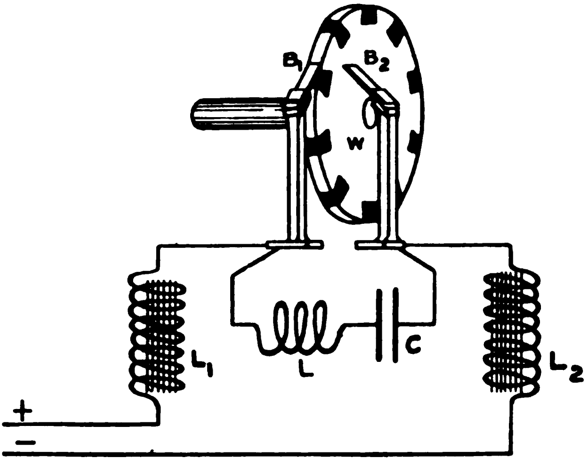


Fig. 172.

W represents a wheel driven round at a high speed by a small motor. In its edge are set a number of insulating segments of mica.

Bearing on its edge and on its side are two brushes, $B_1$ $B_2$, across which is joined the oscillating circuit LC.

Joined to the two brushes are two coils of large inductance $L_1$ and $L_2$.

A D.C. source of supply, interrupted by a hand key, is connected to the two inductance coils.

**347. Action.**—The action of this type of buzzer is very much the same as that of the type previously described.

(*a*) When brush $B_1$ is bearing on a **conducting** segment of the wheel a steady current will flow through $L_1$ and back through $L_2$.

(*b*) When the insulating segment on the wheel comes under brush $B_1$ connection between the brushes is broken. The counter E.M.F.'s. of $L_1$ and $L_2$ (due to the magnetic fields set up round them by the current) will charge up condenser C.

(*c*) When the gap between brush $B_1$ and the next edge of the conducting segment is small enough, the condenser C will discharge in a high frequency oscillation, a small spark gap being formed across a portion of the surface of the insulating segment.

This sparking should occur on the under side of the brush. If it occurs above the brush it indicates that the wheel is dirty, or that excessive power is being used.

Fig. 171 will serve to illustrate also the action of the motor buzzer. The period marked " make " is that during which the brush is bearing on a conducting segment, and the period marked " break " that during which the brush bears on an insulating segment.

This design of buzzer, like the previous type, produces a quenched wave.

**348.** The brushes should bear as firmly as possible on the surface of the wheel, and the standards on which they are mounted should have no play in them.

Causes of bad note and loss of range may be due to excessive sparking at the brush, loose brush holders, or a pitted or dirty wheel.

The condenser will charge up and discharge every time the brush bears on an insulated segment.

Therefore the number of times per second the condenser is charged is equal to the speed of the wheel in revolutions per second multiplied by the number of insulating segments.

**349. The Alternator and Transformer Method.**—The two methods of charging up a condenser just described are only used under the special conditions referred to.

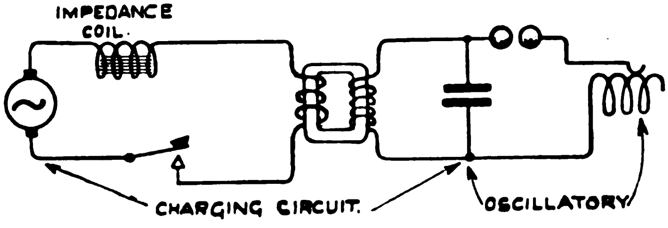
The almost universal practice for energising spark oscillatory circuits of 1/4 kW. sets and upwards is to use an alternator and transformer system.

It is essential to charge up the condenser to a very high voltage, for otherwise we should have to use an excessively big condenser to get a reasonable charge of energy stored up ($Q = CV$), which again would mean that we should be limited to excessively big LC values in the oscillating circuit.

We might get this voltage directly from some **high voltage alternator,** but such machines are very difficult and expensive to construct, and are not at all efficient; also the whole circuit would have to be very carefully enclosed to prevent fatal shocks being taken off it.

Fortunately, as explained in Chapter VI., it is a very easy matter to increase the voltage of an alternating current by utilising a step-up transformer.

Our simplest arrangement is then as shown in Fig. 173, namely, a low voltage alternator (of a power suitable for the



*Charging Circuit.*

FIG. 173.

set we are using) delivering its alternating current at a **frequency** depending on the number of its poles and the speed at which it is run.

**Low Tension Circuit.**—From the terminals of the alternator current will flow through the primary of the transformer and across a signalling key of some sort.

**High Tension Circuit.**—The secondary terminals of the transformer are connected to the oscillating circuit which (as previously described) consists of a condenser, spark gap, and inductance.

The current flowing from the secondary terminals of the transformer will be a **small** one at a **very high voltage,** and at the same frequency as that of the alternator.

NOTE.— As regards the arrangement of the oscillating circuit, it is a matter of indifference whether we take the transformer leads to each side of the condenser, as in Fig. 173, or to each side of the spark gap, as in Fig. 174. Sometimes one arrangement is used, sometimes the other.

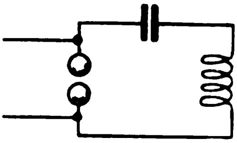


FIG. 174.

### 350. Resonance of the Charging Circuit.

An important question now arises—how shall we utilise the power of the alternator for charging up the condenser to the greatest possible voltage?

We saw in Chapter V. that in any circuit comprising inductance, capacity and resistance, we get the greatest current for a given applied voltage, when we so arrange matters that the natural frequency of the circuit is equal to the frequency of the applied voltage.

This occurs in our charging circuit when f (the applied frequency) $= \frac{1}{2\pi\sqrt{LC}}$, LC being the product of the effective inductance and capacity of the charging circuit.

We then get the condition of resonance, and the current is equal to $\frac{V}{R}$, the counter E.M.F.s of induction and capacity being equal in value and opposite in phase.

The above formula deals with inductance in henries and capacity in farads.

Working in mics and jars, the formula becomes—

$$f = \frac{3 \times 10^7}{2\pi\sqrt{LC}} \text{ or } \frac{4 \cdot 8 \times 10^6}{\sqrt{LC}} \text{ approximately.}$$

**351.** We must therefore so arrange matters that the natural frequency of the charging circuit is the same as the frequency of the alternator.

The inductance and the capacity which we have to consider in the charging circuit are as follows :—

(*a*) The inductance of the alternator (which is of the order of **millihenries**). We cannot vary this in order to obtain resonance, since it is arranged so as to give us a **certain voltage,** and is fixed by the designer.

(*b*) The inductance of the transformer. As we saw in Chapter VI., this is only a small value when the transformer is on full load, as is the condition when we press the key.

(*c*) The inductance of the primary oscillator. This is only included in the charging circuit when the oscillating circuit is arranged as in Fig. 174, and in any case it has a value of a few mics only, and can be neglected.

(*d*) The capacity is that of the main transmitting condenser. This value is fixed, being chosen so as to make possible a certain range of LC values in the primary circuit. (If a very wide range of LC values is required, it is made adjustable in large steps).

The applied frequency—that of the alternator or rotary converter—is chosen so as to give a **distinctive note** for the set in question.

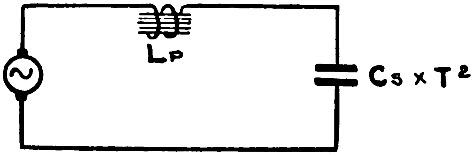
All these factors being therefore fixed by considerations other than that of obtaining resonance, the universal practice is to arrange that the tendency for the current to **lead** is slightly greater than the tendency **to lag**, and then to bring the circuit into resonance by adding an additional inductance on the low tension side of the transformer.

This added inductance is termed, "**The Impedance Coil,**" if it is connected in the low tension circuit (*see* Fig. 173).

(If it is joined on the high tension side of the transformer it is termed a "Choking Coil." This arrangement is rarely used.)

**352.** Before we can decide what value it should have, we must consider what **effect the transformer will have on the LC value of the circuit,** observing that it separates the inductance of the alternator from the capacity of the condenser.

It will be convenient to consider the charging circuit as reduced to an equivalent one in which the transformer is removed, and the condenser connected directly in series with the alternator as in Fig. 175.



*Equivalent Circuit.*

Fig. 175.

It was shown in Chapter VI., para. **289** that a condenser on the high tension side of a transformer may be replaced by one on the low tension side whose capacity is $T^2$ times as great. Therefore, the LC value of our "equivalent circuit" will be $L_p \times T^2 \times C_s$, where

$L_p$ = the sum of the inductances of the alternator, transformer, and impedance coil.
$C_s$ = the capacity of the transmitting condenser, and
$T$ = the transformation ratio.

The formula we must satisfy in order to obtain resonance in the charging circuit thus becomes

$$f = \frac{4 \cdot 8 \times 10^6}{\sqrt{L_p \times T^2 \times C_s}} = \frac{4 \cdot 8 \times 10^6}{T\sqrt{L_p C_s}}.$$

**Example 50.**

(*a*) Find how much inductance is required for resonance in the low tension side of a circuit where the capacity of the transmitting condenser is 16 jars, the step-up of the transformer is 1 : 100, and the frequency of the alternator is 200 cycles.

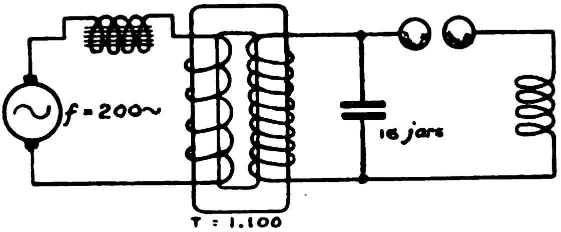


Fig. 176.

$$f = \frac{4 \cdot 8 \times 10^6}{T\sqrt{LC}}. \quad \text{Therefore } \sqrt{LC} = \frac{4 \cdot 8 \times 10^6}{200 \times 100} = 2 \cdot 4 \times 10^2.$$

$$\text{Then } L = \frac{(2 \cdot 4)^2 \times 10^4}{16} = \cdot 36 \times 10^4 = 3{,}600 \text{ mics} = 3 \cdot 6 \text{ mH}.$$

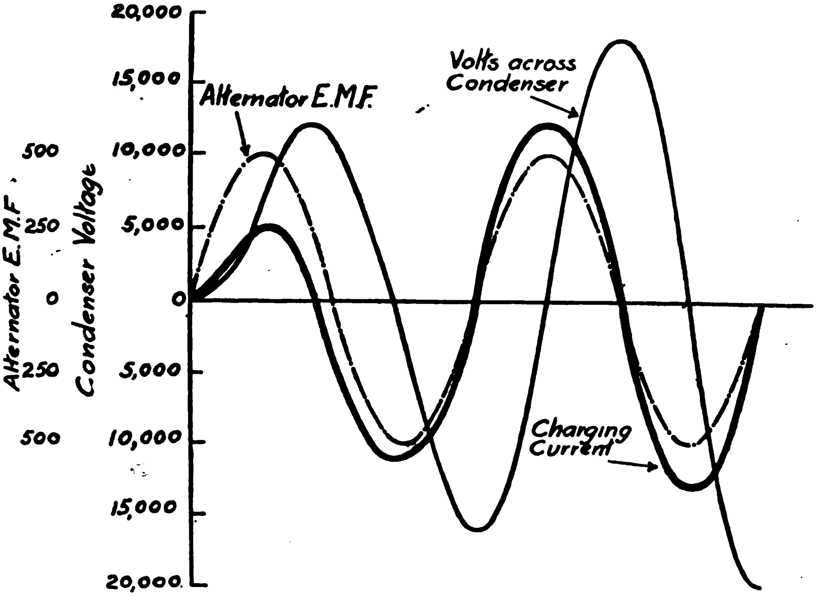
(*b*) If the joint inductance of the alternator and transformer is 2 millihenries, then an impedance coil of **1·6 millihenries** will have to be placed in the low tension circuit in order to obtain resonance.

**353. An Impedance Coil** is an iron-cored coil, generally with a small airgap in its magnetic path; the effect of this is to keep the inductance of the coil constant for various frequencies.

**354. Condenser Voltage under Resonant Conditions.**—By this resonant method of charging the transmitting condenser, we may charge it up to very much greater voltages than merely the alternating voltage multiplied by the step-up of the transformer.

Fig. 177 illustrates how the voltage across the condenser builds up in a few half-cycles after the key is pressed, or rather how it would build up if a spark did not take place.

The energy that is stored in the condenser at its first charge transfers itself to the magnetic field round the various inductances of the circuit as current flows out of the condenser; then when the current falls this energy recharges the condenser, augmented by power from the alternator. Thus the energy surges backwards and forwards and builds up until the limiting condition is reached when the current reaches the value of $\frac{V}{R}$, R being the effective resistance of the whole circuit.



*Resonant Circuit: Initial Condition of Alternator Voltage and Current and Condenser Voltage.*

Fig. 177.

If the resistance of the conductors of the charging circuit is a small value, as should be the case in a well-designed circuit, the current will build up to a very big value indeed after a few half-cycles of the applied E.M.F.

The voltage across the condenser will be equal to $I_2/\omega C$, where $I_2$ is the alternator current divided by the transformer step-up.

**355.** The conditions illustrated in Fig. 177, are those occurring in a certain set when the key is pressed.

The proper resonant frequency is applied by the alternator, and the damping is typical of a well designed set.

From it we can see that when the key is pressed—

(*a*) the current is not quite in phase with the alternator E.M.F. at the first half-cycle, but has got into step at the end of the first cycle, so showing that at that moment the circuit is properly in resonance.

(*b*) the voltage across the condenser quickly rises as current starts to flow into it. At the peak of the first half cycle it reaches a value of 12,000 volts, while in the second half-cycle it reaches a value of 16,000 volts, at the third half-cycle 18,000 volts, and at the peak of the fourth half-cycle it attains its maximum value of 20,000 volts, and is lagging by 90° on the charging current.

**356.** So far we have not considered what effect the spark will have upon this resonant condition.

Actually we find in practice that conditions are not quite so simple as the foregoing, and that in some cases we do not want exact resonance.

(*a*) **A.C. Generator Load Limit.**—In low power sets it is desirable to depart from the true resonant conditions, and to provide rather more inductance than is required for resonance, in order to prevent the alternator or rotary converter from being overloaded.

If true resonance were worked to, the alternator would be continually asked to supply a current much greater than that for which it is designed.

Thus, although the inductance already present in the alternator armature and transformer primary may be greater than that required for resonance, yet, in these sets it is generally necessary to introduce an impedance coil to prevent the A.C. generator from being overloaded.

(*b*) **Avoidance of Arcing.**—When the resistance of the spark gap is broken down, and the high frequency oscillatory current is flowing between the spark plugs, the intense heat generated by the spark at the moment of discharge is sufficient to volatilise some of the metal of which the spark electrodes are made. This volatilised metal, which is a highly conductive vapour, is carried by the current across the gap and forms a conductive bridge from one electrode to the other.

So long as a certain minimum current is passing across the gap it is sufficient to maintain the supply of vapour, and the conductive bridge is maintained; but as soon as the current ceases the surrounding atmosphere rapidly cools the vapour, which condenses on adjacent objects, and the conductive bridge is thus broken up and dispersed.

We want the conductive bridge to last long enough for the high frequency oscillation, but we do not want it to last so long **that the next half cycle of current from the secondary of the transformer starts to flow across the gap instead of flowing into the condenser.**

After the gap has been broken down, as described above, the secondary terminals of the transformer are practically short-circuited.

If it were not for the inductance of the charging circuit, including that of the impedance coil, a very large **alternating current** would flow across the gap **from the transformer secondary,** which would burn up the spark plugs and overload the alternator.

This action is termed " Arcing."

The effect of the charging circuit inductance, however, is no longer balanced by the condenser, since the latter is short-circuited by the spark gap. The sudden rise of alternating current is, therefore, held in check just long enough for the spark to be extinguished and for the insulation of the gap to be restored.

It often pays a designer to make the impedance coil rather larger than is actually required for resonance or for safe load, in order to augment this effect.

Hence for these two reasons, viz., (*a*) to avoid overloading a small machine, and (*b*) to prevent arcing, the impedance coil is sometimes made greater than is required for true resonance.

**357. Spark Train Frequency.**—Let us next consider what happens when a spark occurs. Each time the gap breaks down, an oscillatory discharge of the condenser takes place, and energy is transferred to the aerial circuit and radiated out into space (as described in the last chapter).

The rate at which these oscillations follow one another is termed the " Spark Train Frequency."

We will first take the simplest case of a fixed spark gap. By this is meant a gap in which the plugs are fixed relatively to one another while sparking is taking place, but whose distance apart can be varied before the transmitting key is pressed.

At first sight it might be thought desirable to take the spark at the moment when the condenser voltage is maximum. At this moment, however, the condenser charging current is zero **and about to increase** (*see* Fig. 177).

Thus there would be no time for the train of waves to die away before the charging current started to rise again. The consequence would be that the charging current would maintain the conductive bridge across the spark gap, and **arcing**, with its attendant undesirable consequences, would ensue.

**358.** Now suppose the spark gap is set so as to break down at 15,000 volts. (This would occur when the gap is set at about 5 m.m.).

The first peak value across the condenser, being only 12,000 volts, will be insufficient to break down the spark gap, and the gap will not break down till just before the second peak value

When the spark takes place the gap is short-circuited as long as the high frequency oscillation in the primary oscillatory circuit continues.

This time is very small indeed compared to the time for one cycle of the charging circuit.

For example: suppose the LC value of the primary oscillator is 1023 the natural frequency of the circuit will be 150,000 cycles per second. If the primary oscillation is damped out after 50 cycles, the oscillation in the primary will last $\frac{50}{150,000}$ $=\cdot 33$-thousandths of a second.

The time for one cycle of an alternator giving a frequency of 350 cycles per second is 2·85-thousandths of a second.

The oscillations of the discharge last, therefore, for rather less time than $\frac{1}{8}$ of the cycle in this particular case.

From Fig. 177 we see that when the condenser voltage is 15,000 the charging current is a small value, and is rapidly falling, being zero when the condenser is fully charged.

If, however, we had set the gap so as to break down at 13,000 volts, the charging current would have been much greater, and there would have been a strong tendency for an arc to occur.

From this we learn that it is very important to adjust the alternator voltage carefully to suit the spark length in use, so that the gap breaks down just before the moment of maximum condenser voltage.

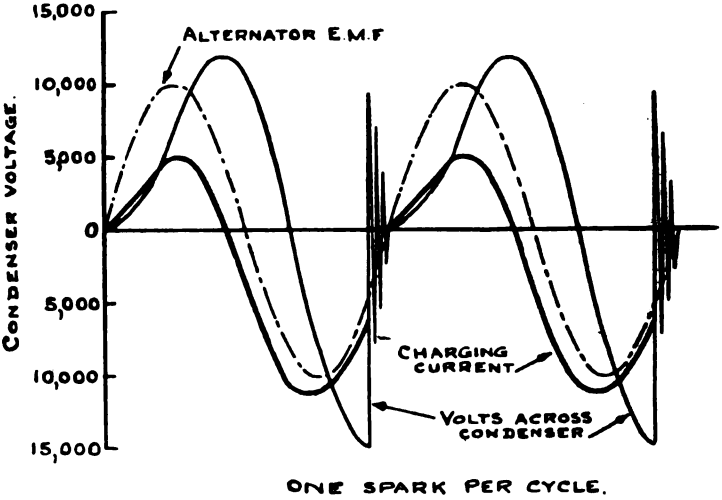


FIG. 178.

**359.** Fig. 178 illustrates what happens when oscillations are occurring.

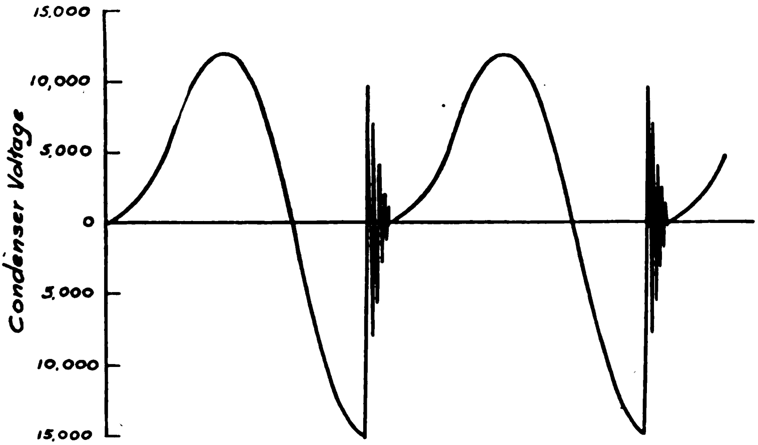
If the spark gap has been adjusted to the correct value, the train of waves will be over before the next cycle of alternator E.M.F. commences.

When it is over, current starts flowing into the condenser once more, and the P.D. across it rises to 12,000 volts at the first half cycle, and at the next half cycle to 15,000 volts, when another oscillation occurs.

We thus get one train of waves per cycle, or a **spark train frequency** equal to the frequency of the alternator, *e.g.*, with a 350 cycle alternator we should get 350 wave trains per second.

As will be seen later, in the chapter on receiving gear the spark train frequency controls the **note** heard by the receiving station. Hence, by varying the frequency of the alternator we can vary the note heard by the receiving station.

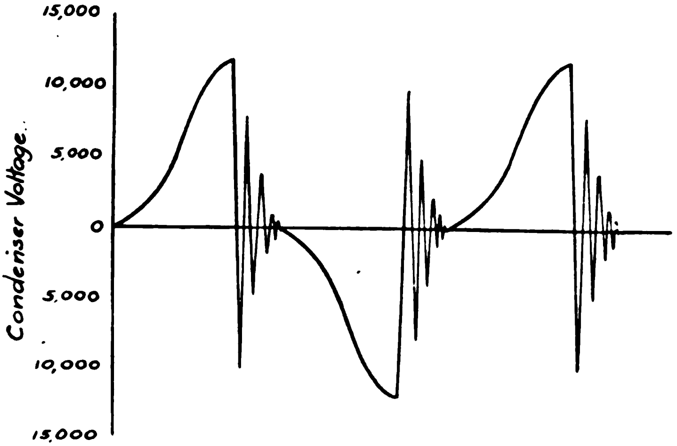
Fig. 179 illustrates the rise and fall of voltage across the condenser, as in Fig. 178, but with the alternator voltage and current omitted.



*One Spark per Cycle.*

Fig. 179.

**360. One spark per half cycle.**—If the spark gap is closed in so as to break down at the voltage reached **during the first half cycle,** *e.g.*, at 12,000 volts, with the conditions illustrated in Figs. 177 and 178, then we shall get a train of waves for each half cycle of current instead of one for each cycle.



*One Spark per Half Cycle.*

Fig. 180.

This state of affairs is illustrated in Fig. 180, although for clearness the duration of the discharge has been exaggerated.

Here the spark train frequency will be **double** the alternator frequency. This is the most usual condition in modern spark circuits.

When the spark is occurring once per half-cycle the spark gap will get just twice as hot as with one spark per cycle, and it will be very difficult to cool it sufficiently to prevent a good deal of arcing occurring.

The only means of doing so efficiently is by the use of a "Rotating Gap" or "Quenched Gap" which are described later.

If arcing does occur, current which should have been flowing into the condenser flows across the gap instead, with the result that the charging of the condenser is delayed, the regular sequence of the wave trains is spoilt, and therefore the note is spoilt, range is decreased, and the spark plugs are rapidly burnt away.

If the gap is reduced so as to break down at a much lower voltage than just before the peak value at either the half-cycle or the cycle, then it does so at a moment when there is a considerable current flowing into the condenser, and bad arcing results.

When using a small spark gap, therefore, **it is very important to reduce the alternator voltage.** This will not alter the sequence of events illustrated in Figs. 178 and 179, but simply reduces the voltage available for maintaining the arc.

**361.** By using a very short spark length, and some means of restoring the insulation of the spark gap very rapidly (such as a rotating gap as described later), it is possible to get as many as **two** sparks **per half cycle.**

This would give us a high spark train frequency with a low frequency supply. A good deal of power will be wasted in arcing, but it may be worth while on account of the ease of reading the high note.

**362. Power taken in charging a Condenser.**—When a condenser C is charged up to a certain discharging voltage of $V_m$ volts, the amount of energy stored up in it is equal to $\frac{1}{2} CV_m^2$ joules.

As we saw previously, this energy is dissipated in various losses in the primary and aerial circuits, while the condenser is discharging in a high frequency oscillation across the spark gap.

If we charge up the condenser to a voltage of $V_m$ volts N times per second (*i.e.*, if N is our spark train frequency), then we shall be expending energy at the rate of $\frac{1}{2} CV_m^2 N$ joules per second.

Now the **rate of expenditure of energy** is termed power; the watt is the electrical unit of power, and is equal to one joule per second.

Hence, to charge a condenser of C farads up to a voltage of $V_m$ volts, N times per second will take a power of—

$$\tfrac{1}{2} CV_m^2 N \text{ watts.}$$

Denoting power in kilowatts and capacity in jars, the following formula is therefore true :—

$$\text{Power in kW.} = \frac{1}{2} \times \frac{C}{9 \times 10^8} \times \frac{V_m^2 \times N}{1000}$$

$$= \frac{1}{2} \times \frac{CV_m^2 N}{9 \times 10^{11}}, \text{ or } \frac{CV_m^2 N}{1 \cdot 8 \times 10^{12}}.$$

where kW. = the power required to charge a condenser of C jars up to a discharging voltage of $V_m$ volts at a spark train frequency of N spark trains per second.

### Example 51.

Find the power required to charge a condenser of 200 jars up to a voltage of 15,000 volts, at a frequency of 300 cycles, with a spark train frequency of one spark train per cycle.

$$\text{kW.} = \frac{200 \times 15{,}000^2 \times 300}{1 \cdot 8 \times 10^{12}} = 7 \cdot 5.$$

### Example 52.

In a certain set the motor driving the alternator is designed to run at a speed of 2,400 R.P.M. with an applied voltage of 100 volts and will stand an input current of 150 amperes. The alternator has 10 poles; the condenser has a capacity of 200 jars; one-third of the power input is wasted in various losses. Find the maximum sparking voltage that could be obtained for one spark per half cycle.

The frequency of the alternator $= \frac{2400}{60} \times \frac{10}{2} = 200$ cycles per sec.

The spark train frequency (N) = 400, at one spark per half cycle.

The power input to the motor is 150 amps. at 100 volts = 15 kW., of which one-third is wasted in various losses.

The power applied to the condenser is therefore $= \frac{2}{3} \times 15 =$ 10 kW.

$$\text{kW.} = \frac{CV_m^2 N}{1 \cdot 8 \times 10^{12}}.$$

Therefore—

$$V_m^2 = \frac{\text{kW.} \times 1 \cdot 8 \times 10^{12}}{C \times N} = \frac{10 \times 1 \cdot 8 \times 10^{12}}{200 \times 400} = \frac{9 \times 10^8}{4}.$$

$$V_m = \frac{3 \times 10^4}{2} = 15{,}000 \text{ volts.}$$

From the above formula we can deduce that—

the (*a*) greater the size of the condenser charged,
(*b*) higher the sparking voltage, and
(*c*) higher the spark train frequency,

the more the power required to charge the condenser up, and the more the power passed to the aerial and radiated away every second, the preponderating factor being $V_m$.

**363. Design of Spark Gaps.**—Charging circuits are very similar in their general arrangements, differing in detail only according to the power of the set and the range of waves required.

It is chiefly in **design of spark gaps** that sets differ.

The objects aimed at may be classified as follows :—

**364. (A) To prevent Arcing.**—The effect of arcing has been described already.

Our first object is so to cool the conductive bridge that it is readily extinguished as soon as the oscillatory discharge of the condenser is over.

**365. (B) To effect "Quenching."**—Certain designs of gaps aim at putting the spark out even more quickly than this.

We saw in Chapter VII., that when the primary oscillator has transferred its energy to the aerial, the aerial re-transfers it back to the primary, and the energy is transferred and re-transferred backwards and forwards between the two circuits until it has been entirely expended in various damping losses, as illustrated thus—

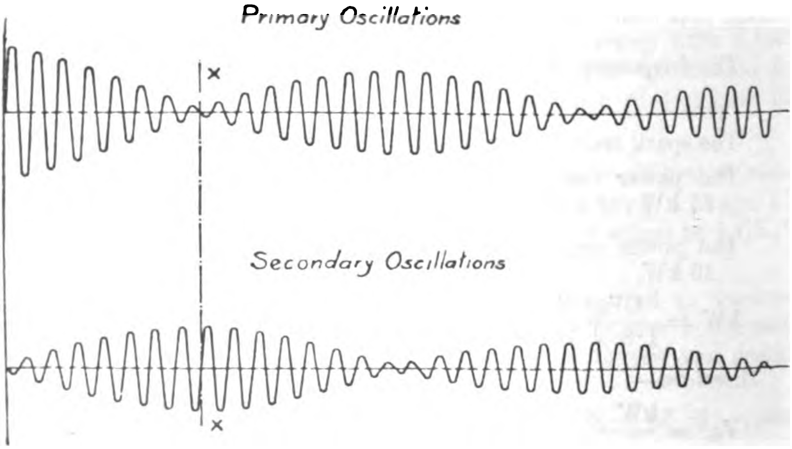


*Diagram of Primary and Aerial Currents in Ordinary Coupled Circuit.*

FIG. 181.

This transfer and re-transfer of energy produces two harmful results :—

(*a*) The heavy damping of the spark gap is wasting the energy of the high frequency oscillation the whole time.

(*b*) Two waves are emitted which interfere with ships working on other waves of slightly different value.

If, in some way, we can manage to put the spark out at the moment X in Fig. 181 (when the primary energy is at a minimum), then the conditions are entirely changed.

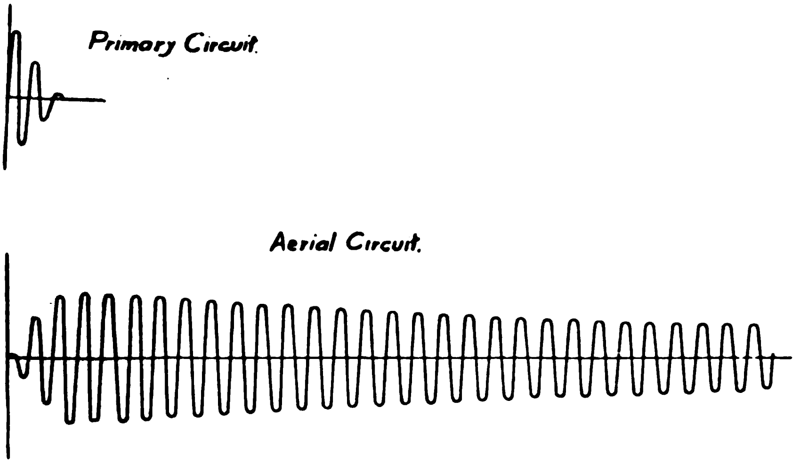
As soon as the whole of the energy has been transferred to the aerial the conductivity of the gap is destroyed and the energy which is now in the aerial cannot return to the primary, and will therefore continue to oscillate in the aerial circuit until the whole of it has been radiated in the form of electromagnetic waves or lost unavoidably in resistance in the aerial circuit.

In this case, the diagram of the current oscillations which occur in the two circuits will be as shown in Fig. 182.

The upper diagram represents the oscillations in the primary circuit until the spark is " quenched " at the moment X, and the lower diagram those in the aerial circuit.

A spark having these characteristics is known as a " Quenched Spark," and the result of coupling the two circuits together under these conditions is the **production of a single wave,** because as soon as the spark is quenched, which occurs after the first three or four oscillations, the aerial circuit is free to oscillate at its own natural frequency.

Quenching is only achieved by the use of the " Quenched Gap," and by buzzers as already described.



*Primary and Aerial Currents in Quenched Gap Circuit.*

FIG. 182.

**366. (C) To produce a High Spark Train Frequency.**—The note heard in the telephones at the receiving station depends on the spark train frequency of the transmitting station.

If a fairly high frequency alternator is used, the conditions of one spark per cycle will give a high note.

If, however, the alternator or rotary converter is a low frequency one, we may increase the spark train frequency by using such a short spark length as to give one spark per half cycle or even two sparks per half cycle. It will be necessary in this case to take very special precautions to eliminate arcing troubles.

## Various Spark Gaps in use.

**367.** The various types of spark gap in use may be classified as follows :—

(*a*) **Gap with Fixed Electrodes.**—By this is meant a gap in which the plugs are fixed relatively to one another while sparking is taking place, but their distance apart can be set to any required length before the transmitting key is pressed.

Various shapes are illustrated in Fig. 183.

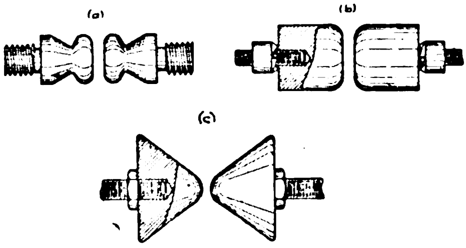
Such gaps are quite suitable for low power, or for low sparking frequencies, and are simple, requiring little attention beyond a periodical cleaning.

" Quenching " is not effected, however, and two well-marked waves will be emitted.

A good deal of arcing will also take place if an unduly short gap is used, while if the gap is opened out too far its damping effect will be excessive.

For higher powers or higher spark train frequencies, a **Blower** is often provided to prevent arcing troubles.

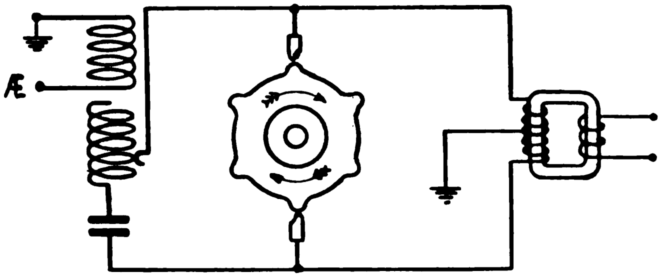
This is an arrangement for forcing a powerful blast of air between the electrodes; it consists of a high speed electrically-driven fan forcing air through a small porcelain nozzle, placed just below the centre of the gap.



*Fixed Spark Gaps.*

FIG. 183.

**368.** (*b*) **Asynchronous Rotary Gap.**—By this is meant a wheel carrying a number of studs or spokes projecting from its edge, revolving at a high speed between two fixed electrodes (as illustrated in Fig. 184).



*Asynchronous Rotary Gap.*

FIG. 184.

It is rotated by means of a small motor, which drives it either directly, or through a flexible belt.

The word " asynchronous " means that its speed of revolution bears no relation to, or is out of time with, the speed of revolution of the alternator.

The gap between the fixed and moving electrodes is adjusted to be as small as possible.

A spark will occur whenever the gap between the fixed electrodes and the two points approaching them is small enough for the condenser voltage to force a spark across it.

The path of the oscillating current will be through the two gaps in series and across the wheel.

By using such a small gap we are able to get a high spark train frequency from a low frequency source of alternating current.

Any arcing is very rapidly extinguished owing to the high speed of the wheel and the draught of air.

The drawback to this type of gap is that the note produced at the receiving station is not an absolutely pure one, for the following reason :—

It often happens that the moving studs come opposite the fixed ones at a moment when there is no charge at all in the condenser, and a train of waves is missed.

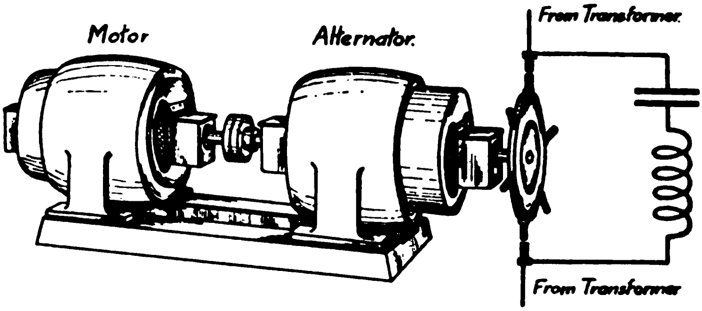
Consequently, when the next pair of moving studs approach the fixed ones, the condenser has an extra charge in it and sparks over a longer gap, and at an earlier moment than that of the preceding spark.

Conversely, the moving studs may approach the fixed ones at a moment when the condenser voltage can only break down the air gap when the points are absolutely opposite one another, and the wave train is a little late.

The wave trains thus succeed one another at intervals which are not absolutely regular, some being a little early and others a little late; this results in a note at the receiving station which is not a pure one.

It is impossible to attain anything like resonant conditions in a circuit where an asynchronous gap is used to obtain a high sparking rate with a low frequency alternating current, since the condenser is occupied in discharging for such a large proportion of each cycle of the alternating current.

**369.** (*c*) **Synchronous Rotary Gap or Disc Discharger.**—A **Synchronous Rotary Gap** denotes a form of design in which the rotating wheel is carried on an extension of the alternator shaft. (Fig. 185).



*Motor Alternator with Synchronous Rotary Gap.*
FIG. 185.

The disadvantage of the asychronous gap is thus obviated, for as the speed of the wheel and the alternating frequency both depend on the speed of revolution of the motor driving the alternator, the charges put into the condenser per second and the opportunities it has of discharging per second can be timed to suit one another. (This fact is indicated by the word " Synchronous," which means " in time with.")

As the number of cycles per revolution of the alternator is equal to the number of **pairs** of its poles, and as in one revolution of the spark wheel the number of opportunities of sparking is equal to the number of studs on the wheel, it follows that if we want to get **one spark train per half cycle** the wheel should have as many studs as the alternator has poles; for two sparks per half cycle the wheel should have twice as many studs as the alternator has poles, and so on.

As we saw previously, it is always desirable to arrange that the spark shall occur just before the moment when the condenser is fully charged and the current flowing into it is zero.

This can be arranged by altering the position of the fixed studs relatively to the field poles, and so altering the sparking moment relatively to the cycles of the alternating current and condenser voltage.

To effect this the fixed studs are mounted on a rocker which can be traversed in one direction or the other.

The adjustment is easily made by pressing the key and watching the moving studs; when set at the correct position the spark will always take place at a moment when the moving and fixed studs are at the same distance apart and therefore they appear to be at rest as the sparks illuminate them; if incorrectly set they will be in different positions at each spark, and will therefore appear to stagger about.

The advantages of a synchronous gap are as follows :—

(i) The discharge will commence when the distances between the revolving and fixed electrodes is short enough to allow it, a distance which depends on the potential used and the capacity of the condensers; it will commence before the two gaps are short enough to allow of arcing, and at the same time there will be no missing of sparks, for if the voltage is lower than usual, the discharge simply commences a little later, when the electrodes are a little nearer to each other.

(ii) After the discharge commences the moving electrodes are passing the fixed ones; the spark gaps are then shortened and have less resistance, thus decreasing any damping effect which would be due to spark gap resistance in the primary circuit. There will be no arcing with the shortened gaps, for the condenser charging current has now fallen to zero. We thus get regular sparking without any misses, therefore a pure musical note; and arcing is absolutely prevented.

It is claimed that the high speed of the break also effects quenching, but this is not entirely borne out in practice, at any rate with small sets.

The drawback to the synchronous rotary gap is that it—and consequently the motor alternator—must be close to the primary oscillator, in order to avoid excessively long leads from the oscillating circuit to the spark gap.

It will not, therefore, be possible to receive when the alternator is running unless it is enclosed in an absolutely sound-tight casing.

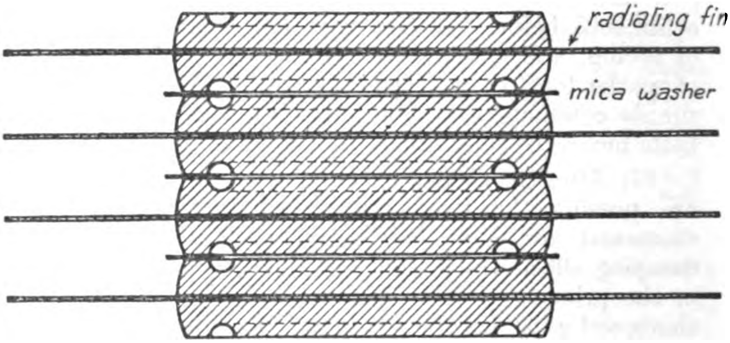
**370.** It should be noted that the motor buzzer wheel, as previously described, is only a special variety of a synchronous gap. As the supply is a direct current one, the spark train frequency is entirely dependent on the speed of revolution.

The limitation of the motor buzzer is that it can only deal with small charging currents without arcing occurring.

**371.** (*d*) **The Quenched Gap.**—We have already explained that quenching is simply a matter of cooling the spark path rapidly enough.

A method of accomplishing this is by making use of the property metals have of conducting heat. By dividing a spark gap up into a sufficient number of very short gaps in series with one another, and arranging that the electrodes have ample section of metal for conducting the heat away from the spark very rapidly, and that they have plenty of surface exposed to the surrounding air for radiating the heat away, any desired degree of quenching can be obtained.

The quenched gap, or "singing spark" as it is sometimes called, has been adopted by the Telefunken Company as a characteristic part of their system. As made by them it consists of a number of metal discs, with grooves cut in them as shown in Fig. 186, each disc slightly recessed at the centre.



Quenched Gap Discs

FIG. 186.

The discs are separated by very thin insulating washers of mica, which extend only a little way across the grooves.

The thinner these washers are the purer the wave at which the energy is radiated, so that the mica used is only $\frac{1}{10}$ to $\frac{3}{10}$ mm. thick.

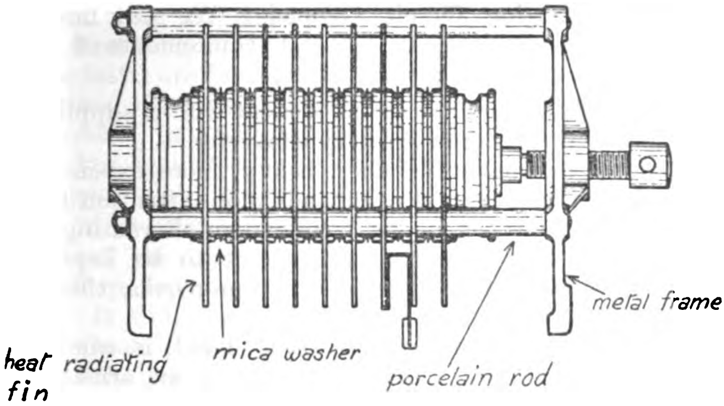
The spark will start at any part of the inner portions of the discs, and owing to the action of the magnetic fields which are set up by the discharge current, it is rapidly driven outwards towards the grooves, where it becomes lengthened and extinguished.

Fig. 187, shows a complete Quenched Spark Gap consisting of eight units; some of the units, if necessary, may be cut out of action by short-circuiting them with metal spring clips, seen in the illustration.

It is necessary to adjust the alternator voltage very carefully to suit the number of gap units in use.

**372.** By means, then, of subdividing the spark gap in this manner, the resistance of the gap is maintained at a very high value, and the spark goes out very quickly.

In order to transfer the energy from the primary to the aerial before the spark goes out, it is necessary to use an exceedingly tight coupling to the aerial circuit.



*Quenched Gap.*

FIG. 187.

The coupling used is generally a "direct" one, of the order of 20 to 30 per cent.

The best results are obtained when the aerial is slightly mistuned to the primary.

### 373. Advantages of the Quenched Gap.—

(*a*) As the energy is not re-transferred from the aerial to the primary after the gap quenches, no interaction occurs between the two circuits, and for the greater part of the wave train the aerial only radiates one wave, viz., that due to its own natural frequency.

(*b*) Owing to the very short duration of the spark, the gap is peculiarly suitable for use with a high frequency alternator, and will readily give one spark per half cycle if properly adjusted, since there is no tendency to arc.

For use in commercial stations, the Telefunken alternator is generally built for a frequency of 500 cycles per second, which at one spark per half cycle gives a spark train frequency of 1,000 per second. This high spark train frequency is peculiarly suitable for reading through bad atmospherics, but is rather tiring to the ear.

(*c*) Although the resistance of the gap is very high, yet it is in circuit for a very short time compared to the long duration of the oscillation in the aerial.

Consequently, the efficiency of the generation of oscillations and their transference to the aerial is very high.

**Disadvantage.**—Owing to the very tight coupling that must be used between primary and aerial. the aerial oscillation starts off with a very big initial amplitude, and has a double frequency at the commencement of the wave train. This has a very serious shock effect on neighbouring aerials, which entirely invalidates the system for the requirements of the Naval Service.

**374. The Charging Circuit Complete.**—We are now in a position to discuss broadly the general requirements of a Spark Transmitting installation (*see* Fig. 189.)

**Power Supply.**—The alternating current will be supplied from either a motor alternator or a rotary converter.

The motor alternator is bulky, heavy, more expensive, has several bearings, and generally demands more attention than the rotary. It can, however, be made to give an alternating voltage of high value, thus enabling the current to be kept within convenient limits in high-powered sets; moreover, the voltage can be varied to suit the spark length in use.

The rotary converter, on the other hand, is small, light, cheap and simple. It has but two bearings, one armature and one set of field magnets; it has, however, a limited and unvariable voltage.

If the power supply is from a set of accumulators, and not from a constant voltage dynamo, a motor alternator must be installed, since if the accumulator voltage falls off, the A.C. voltage from a rotary converter would also fall off, perhaps to a value which would not give any appreciable transmitting range. On the other hand, with a motor alternator, a decrease in input volts and therefore in motor speed can be compensated for by an increase in the alternator field current.

Duplicate machines are generally supplied in H.M. ships placed in separate watertight compartments, and fed through duplicate starters from either side of the ring main system.

Normally, the machine in use should be fed from the section of the ring main on the disengaged side in action.

With both motor alternators and rotary converters, a **Starter** will be necessary, with a no-volt-release coil, and some arrangement to prevent an excess current being taken from the mains. This may take the form of a cut-out in one main, or of an overload release coil on the starter.

**A Motor Field Regulator** will be provided for varying the speed, and therefore the alternating frequency. (As previously explained, the voltage of the alternating current supplied by a **rotary converter** will always remain about 65 per cent. of the supply voltage, whatever the speed.)

An **A. C. Ammeter** and a **Frequency Meter** will also be provided: With a motor alternator, a **D.C. Ammeter and an A. C. Voltmeter** will be supplied; also an **Alternator Field Regulator**, in order to vary the voltage of the alternating current.

**375. Frequency Meter.**—This is an instrument arranged to show the variations in frequency between such limits as those for which the speed of the machine is designed.

Essentially it consists of an electro magnet with an open magnetic circuit and laminated core energised by a high resistance winding, whose inductance is small compared with its resistance.

The core of this magnet becomes magnetised twice every cycle, and these magnetic pulls are felt by every one of a row of small steel tongues.

These latter are fixed at their inner ends and are free to vibrate in a vertical direction at their other ends, each tongue having been " tuned " like a tuning fork, to vibrate at such a frequency as is marked against it.

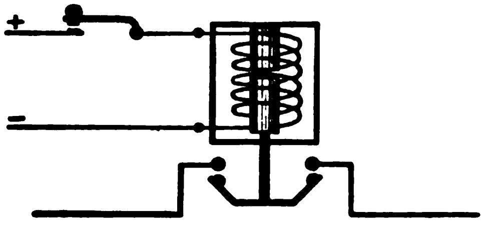
The particular frequency at which any tongue will oscillate depends on its mass and elasticity.

Since all the tongues are pulled equally, one of them will find itself pulled at intervals corresponding to its own time period. It will, therefore oscillate violently, so much so that its end, which is turned up and painted white, appears, not as a white dot, but as a grey band against the black interior of the instrument.

From the slip rings of the machine in use come the A.C. mains in series with which we shall have the Signalling Key, an Impedance Coil, a safety arrangement of some sort, and finally, the primary of the step-up transformer.

**376. Signalling Key.**—If the alternating current is small and its voltage is low, signalling may be effected by making and breaking the alternating current circuit by means of a hand key. (*See also* para. 387.)

If, however, the current is too great, or the voltage of a dangerously high value, a **Magnetic Key** will be used. This consists of a single pole break between two contacts which is short-circuited by a moving contact. The key is energised by direct current being supplied to the bobbin of a solenoid when a hand key is pressed, as illustrated in Fig. 188.



*Magnetic Key.*

FIG. 188.

When the low tension current is too great to be interrupted conveniently, the magnetic key may be placed in the high tension circuit, but special precautions must then be taken about its insulation.

The drawback of this arrangement is that, even when the key is not pressed, the secondary terminals of the transformer are alive.

It is used in certain high power shore stations.

**377. Safety Arrangements.**—It is necessary to prevent the operator from accidentally receiving a fatal shock.

For a shock to prove fatal about one-eighth to one-sixteenth of an ampère of direct or low frequency alternating current will be necessary, one ampère being certainly enough to kill a man; far heavier currents at high frequency, however, can be safely withstood.

The resistance of the human body varies in different individuals with the degree of moisture of the skin; and also the danger of the shock will depend on the state of health; but normally, the resistance of a man from one hand to the other is about 20,000 ohms. A very much worse shock is taken if the terminals of the mains are firmly grasped with the hands, or held in a pair of pliers, than if they are only touched with the finger tips.

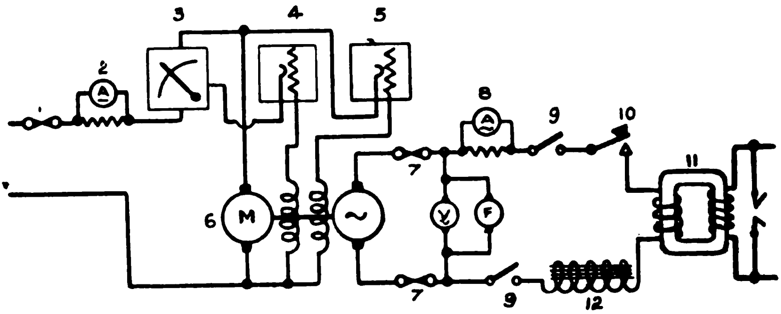
Thus any voltage above 1,250 volts direct or low frequency current will probably prove fatal, but voltages of 500 and above would be dangerous.

If the alternator voltage is below 220 volts, the high tension side of the transformer, the primary oscillating circuit, and the aerial circuit will be the only dangerous parts of the circuit.

These may be protected by enclosing the transformer oscillating circuit and aerial coil in a cage, and arranging that the cage cannot be opened without breaking the low tension alternating current circuit at one point at least. It is better if both mains are broken. Thus, if the key is pressed when either cage door is open, nothing will happen.

If, however, the alternating voltage is high, it will be necessary to arrange in addition that it is not possible to receive a shock from the alternator mains.

This can be effected either by placing the various instruments included in the low tension circuit inside the safety cage, or by enclosing them in boxes the lids of which cannot be opened when the primary circuit of the alternator is alive.



*Typical Low Tension Circuit.*

Fig. 189.

**378. Low Tension Circuit.**—Fig. 189 represents a typical arrangement of a Low Tension Circuit.

1 is a cut-out in the positive D.C. main.

2 is a D.C. Ammeter with its shunt.

3 is a starter for the motor of the Motor Alternator (6).

4 is the Motor Field Regulator.

5 is the Alternator Field Regulator.

6 is the Motor Alternator: (if a Rotary Converter is supplied in lieu, then the Alternator Field Regulator (5) and field magnet winding will be omitted).

7, 7 are A.C. cut-outs, one in each A.C. main.

8 is the A.C. Ammeter with its Shunt.

V & F are respectively the A.C. Voltmeter and Frequency Meter.

9, 9 are the breaks in the low tension A.C. circuit, completed when the cage doors are closed.

10 is the hand key for signalling. If the A.C. current is large, this is replaced by a magnetic key.

11 is the Transformer.

12 is the Impedance Coil.

If power is obtained from a Rotary Converter, then the A.C. Ammeter and Voltmeter may be omitted.

**379. High Tension Circuit.**—The high tension circuit comprises the secondary of the transformer, the leads to the primary oscillating circuit, and the oscillating circuit itself, made up of primary condenser, primary inductance and spark gap.

In this circuit it is necessary to protect the transformer and condenser against excessive strains on their insulation, which may arrive in several ways.

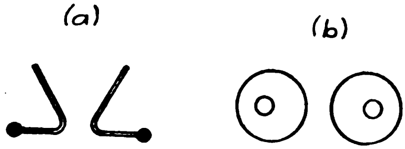
These risks, and the methods of guarding against them, are as follows :—

**380. Safety Gaps.**—The transformer is protected against any excessive rise in its own voltage by having safety gaps fitted across its terminals.

The gap is so arranged that if the terminal voltage of the secondary rises above its normal working limit, then an A.C. metallic arc will form across the gap.

Typical safety gaps are shown in Fig. 190.

Fig. 190 (*a*) consists of two bent pieces of copper wire. Fig. 190 (*b*) consists of two brass discs, mounted eccentrically so that the gap length can be adjusted by rotating them.



*Safety Gaps.*

FIG. 190.

The arc will rise, on account of its own heat, sliding along the wires. The higher it rises the longer becomes the gap which it must bridge, so that it automatically breaks down.

The gap must be kept set at the exact distance laid down in the Handbook for the set in question.

In the same way the transmitting condenser is fitted with safety gaps to prevent it being punctured by any abnormal rise of voltage.

It is commonly the practice, where several sections of a condenser are employed in series, to earth the centre point of the central sections.

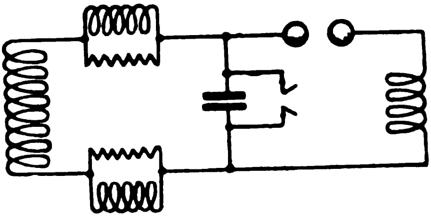
This equalises the capacity to earth of each element of the condenser.

**381. Back Oscillations.**—When the condenser discharges across the spark gap, it is quite possible that some of the high-frequency oscillatory current, instead of flowing across the spark gap, will try to flow back through the secondary of the transformer.

This is a form of trouble known as "Back Oscillations."

If this high frequency oscillation is applied directly to the secondary turns of the transformer, it will set up a very big $\omega LI$ voltage to earth across the end turns, and the insulation of the transformer might easily be broken down.

To prevent this, coils of wire, termed "Protecting Coils," of about 200 to 300 mics inductance, are placed in series with each main (Fig. 191).



*Protecting Coils and Resistances.*

FIG. 191.

The back E.M.F. of these coils to the **low frequency charging current** is very small indeed, nor does the addition of a few mics disturb the resonance of the charging circuit.

On the other hand, when the **high frequency discharge** tries to send some of its current back along the high tension mains, the reactance of the protecting coils becomes so large that they practically form insulators to high frequency currents. (The insulation of these coils may be punctured, but they can easily be re-wound on board.)

Now, protecting coils alone, under certain circumstances, have proved worse than useless.

Being mounted on a baseboard, the two coils have a certain small capacity effect between them; also, each coil has a certain self-capacity of its own.

This capacity, combined with the inductance of the two coils, forms an oscillatory circuit which may happen to have the same LC value, and therefore the same natural frequency as that of the primary oscillator.

Should this happen, then resonant currents will be set up in the protecting coils, and high frequency currents will be impressed on the end turns of the transformer windings, with the result that those turns will have their insulation punctured.

To avoid this, the protecting coils are shunted with non-inductive resistances in the shape of **Carbon Rods**, upon which the energy of the high frequency currents is expended.

The high frequency current sets up a big P.D. across the inductance, which consequently tries to force a big current through the resistance, and the back oscillation is damped out.

**Example 53.**

Two currents, one at a frequency of 350 cycles, and one at a frequency of $\frac{3 \times 10^6}{2\pi}$, are applied to a combination of 1 millihenry in parallel with a resistance of 10,000 ohms.

(a) *Low Frequency Current.*—The reactance of the inductance to the low frequency current $= 2\pi fL = 2 \times \frac{22}{7} \times 350 \times \frac{1}{10^3}$ $= 2 \cdot 2$ ohms.

Thus the inductance forms an easy path for the current, the voltage drop across it is small and consequently the watts expended in the resistance are small: in other words, the inductance short circuits the resistance.

(b) *High Frequency Current.*—The reactance of the inductance to the high frequency current $= 2\pi fL = 2\pi \times \frac{3 \times 10^6}{2\pi} \times \frac{1}{10^3} = 3{,}000$ ohms.

The reactance of this path is therefore comparable to that of the resistance, which is thus no longer short circuited: the combination will cut down to a negligible value any high frequency current that takes this path in preference to that of the oscillating circuit.

**382. Design of the Oscillatory Circuit.**—The oscillatory circuit must be arranged so as to provide a certain range of LC value, which depends on the purpose for which the set is designed.

For example, a set might be required to give a range of all LC values between 50 and 1,200, which would give a range of waves between 444 metres and 2,176 metres.

This might be arranged by having a condenser of 50 jars and an inductance which could be varied between 1 mic and

24 mics, but this would be bad electrical practice for the following reason :—

The energy stored in a condenser of C farads when it is charged up to a discharging voltage of $V_m$ volts is equal to $\frac{1}{2} CV^2_m$ joules.

From this it follows that the larger a condenser we use, the smaller the charging voltage required, to store a given amount of energy in it.

Now $V_m$ represents the voltage at which the spark gap breaks down, and if we make C small and have to use a long spark gap in consequence, this long spark gap will have a heavy damping effect on our train of waves.

Consequently, we want to use the largest possible condenser and the smallest possible inductance.

A much better arrangement would be to provide a condenser composed of two elements of 100 jars each, which could be joined in series or in parallel by means of suitable links.

The capacity of the condensers in the series position would be $\frac{100}{2} = 50$ jars, and in the parallel position $100 \times 2 = 200$ jars.

A primary inductance which could be varied between one and six mics would give a range of 50 to 300 LC with the condensers in the series position, and 200 to 1,200 LC in the parallel position.

If the required range of LC is small, it is unnecessary to introduce the complication of the adjustable condenser, and a condenser of fixed value would suffice.

**383. The Condenser.**—The condenser must be made with adequate dielectric strength to stand the greatest sparking voltage that is likely to be used. For instance, if the condenser referred to above is required to stand an eight millimetre spark, and if one sheet of the dielectric used in it will only stand two millimetres safely, it would be necessary to make up the two elements of 50 jars each by joining four sections of 200 jars each permanently in series, It would therefore be composed as follows :—

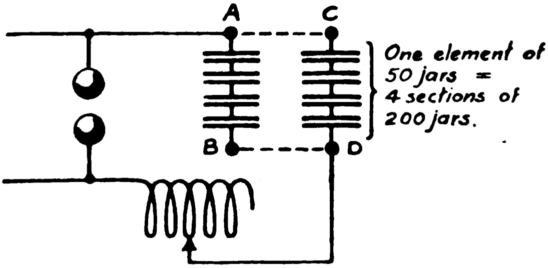


FIG. 192.

To join the two elements in series, connect terminals B and C together.

To join the elements in parallel, connect A to C and B to D.

The dielectrics generally used in the Service for spark transmitting condensers are ebonite, glass or mica.

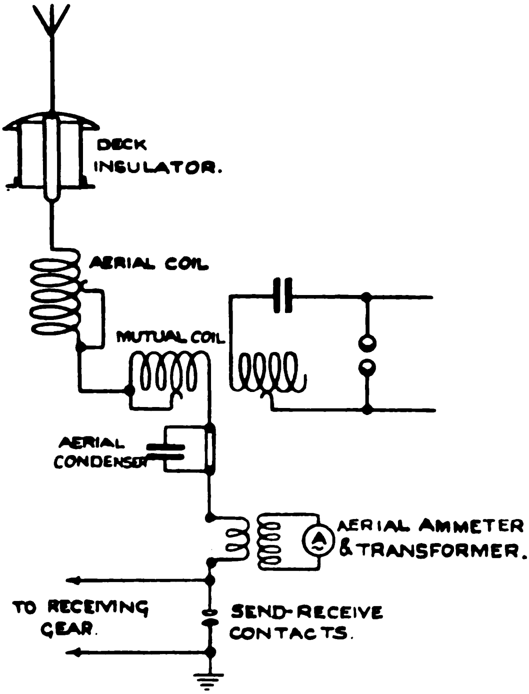
The elements and sections composing the condenser are contained in an iron tank, which is kept brim full of oil, to prevent brushing over the plate edges, and to keep the condenser cool.

However efficient a condenser is made, certain losses in it are unavoidable. These losses have been referred to before in Chapter III., and are referred to under the general heading of "Hysteresis Losses."

When a condenser is being charged up and discharged, it gradually gets hotter and hotter as a result of these losses.

Arrangements have to be made for this heat to be radiated away, and also for the oil to expand without forcing its way under the edge of the lid.

**384. The Primary Inductance.**—This is a coil of copper tubing or flat copper strip, of large surface area, and is so designed in order to obtain low resistance for high frequency currents with a given required inductance and mechanical rigidity. It must have a surface area adequate for the maximum oscillatory currents it will be required to carry.



*Typical Aerial Circuit.*

FIG. 193.

The turns must be spaced sufficiently far apart to prevent sparking over between adjacent turns.

An adjustable connection, of very low resistance, must be provided so that the inductance in circuit can be varied gradually from the minimum to the maximum value, in order to give any required LC value between the limits for which the circuit is designed.

**385. The Aerial Circuit.**—This circuit, illustrated in Fig. 193, comprises the following :—

**Aerial, Feeders, and Deck Insulator,** which are fully described in Chapter XVI.

(*a*) **The Aerial Coil.**—The aerial coil is provided for increasing the LC value of the aerial circuit when transmitting waves longer than the fundamental wave of the aerial.

In spark transmitting circuits it is made of stout copper wire, the turns of which are wound on a former of insulating material, and are spaced sufficiently widely apart to prevent sparking over between adjacent turns.

An important question arises as to whether the idle turns of the aerial coil, *i.e.*, those not required for the particular wave-length in use, shall be short-circuited as in Fig. 194 (*a*), or left an open circuit, as in Fig. 194 (*b*).

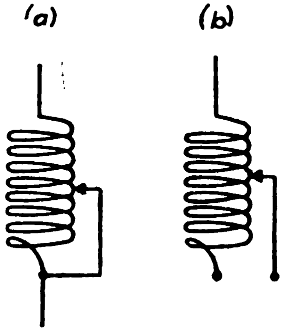


Fig. 194.

If **short-circuited,** the arrangement amounts to a step-down auto-transformer, with its secondary terminals short circuited.

The voltage in the idle turns will be small, but the current in them will be stepped up, and may be very great.

If left on **open circuit**, the arrangement is a step-up auto-transformer, so that the voltage across the whole coil and between adjacent turns will be great.

The general practice is to short-circuit the idle turns of coils used in spark transmitting sets.

When making a tuning connection on the aerial coil, it is important to remember that all the current of a received signal has to pass through it, and therefore to make a thoroughly clean and tight connection.

(*b*) **The Mutual Coil.**—The mutual coil is provided to transfer the high frequency oscillations generated in the primary into the aerial circuit.

It is made adjustable so that it can be brought close to the primary inductance, or moved further away from it, for the purpose of varying the coupling.

In some circuits it is also made adjustable for inductance.

The loosest possible coupling consistent with giving readable signals to the receiving station should always be used.

It is better to use a long spark and a loose coupling rather than a short spark and a tight coupling.

(*c*) **The Aerial Condenser.**—For transmitting waves shorter than the fundamental wave of the aerial, a **series condenser** is generally used, being short-circuited with a link when not required.

**386.** (*d*) **The Aerial Ammeter.**—In order to enable an operator to tell that his circuits are correct, a hot wire ammeter, termed the " Aerial Ammeter," is provided.

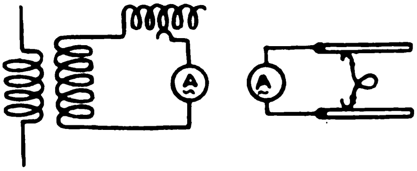
If joined directly in series with the aerial, it would have to be unduly large to carry the full aerial current in most aerial circuits.

It is therefore usually joined across an " ammeter transformer," as in Fig. 193. This is an air core transformer, which steps voltage up, and current down.

The current is thus reduced, so enabling a moderate-sized ammeter to be used, whose scale readings may be multiplied by the transformation ratio of the transformer in order to obtain the true aerial ampères.

Sometimes a variable inductance coil is joined in series with the ammeter, as in Fig. 195 (*a*), so that the ammeter can safely be used for reading large or small aerial currents.

In some sets a shunt is met with in lieu of the ammeter transformer. This consists of two copper rods joined by a slider, as in Fig. 195 (*b*). In this case the ammeter reads the voltage drop across the shunt.



(*a*) *Ammeter Transformer with Choke.* (*b*) *Ammeter Shunt.*

FIG. 195.

An indication is thus given of the aerial current, but the exact value of the current is not known, as the slider is made moveable, in order to cater for aerial currents of widely differing values.

**387.** (*e*) **Send-receive Contact.**—This consists of a make-and-break in the earth lead, across which the receiving gear is joined.

When the transmitting key is pressed this break is short-circuited, thus short-circuiting the receiving gear, and connecting the mutual coil to earth, for transmitting purposes.

When the transmitting key is released the break is opened, thus putting the receiving circuit in series with the aerial.

This allows for what is termed "Listening through," *i.e.*, listening between the Morse signals of one's own message to see whether anyone else is transmitting at the same time.

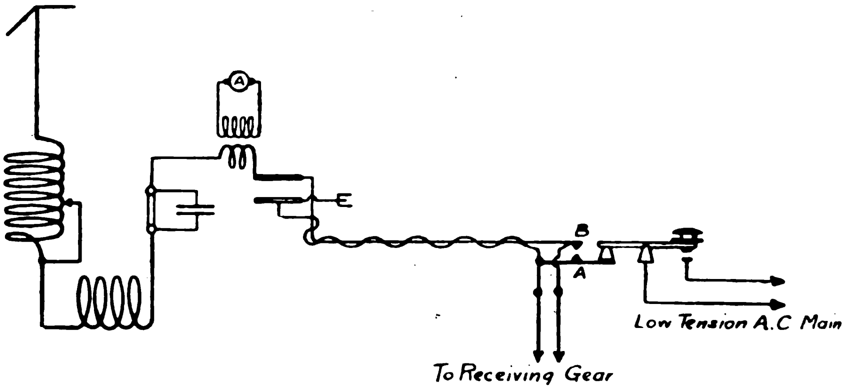
The requirements of the break are:—

(*a*) It must make before, and break after, the low tension charging circuit, to obviate the risk of sparking into the receiving gear.

(*b*) It must either be very close to the earth connection or be joined to it by a non-inductive lead. If there were a long inductive lead between it and earth the voltage across it would be considerable, and the break would have to be a long one to prevent sparking taking place across it as it is made and broken.

A suitable arrangement is illustrated in Fig. 196. Here we have a hand key, fitted with two "back contacts," A and B. Contact A is carried on a flexible springy piece of copper.

A and B are connected to aerial and earth by a non-inductive lead of concentric cable, and across them the receiving circuit is joined. When the key is at rest an ebonite thimble on the toe of the key is bearing on the end of the copper strip that carries contact A. The aerial is then connected to the receiving gear.



"*Listening-through*" *Device.*

Fig. 196.

When the key is pressed, however, its first motion allows A and B to make contact, and thus to complete the aerial circuit to earth, and to short-circuit the receiving gear before the "heel" contacts make.

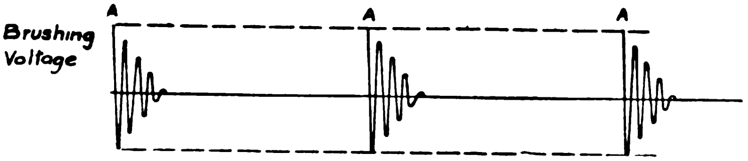
Its further motion closes its "heel" contacts, and completes the low tension A.C. circuit.

## CHAPTER IX.

## THE POULSEN ARC.

**388. Continuous Waves.**—So far we have been discussing the spark system of energising an aerial for transmitting purposes, in which a condenser is charged up to a certain high potential at regular intervals, and allowed to discharge freely across a spark gap, setting up a high frequency oscillation in a closed oscillating circuit, which transfers its energy to an aerial circuit.

The resulting wave trains set up in the aerial are as illustrated in Fig. 197.



*Damped Wave Trains.*

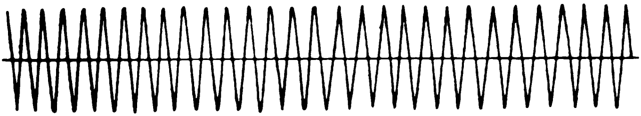
FIG. 197.

These are spoken of as "damped wave trains," and they follow one another at the "spark train frequency," which depends on the frequency with which the primary condenser is charged up to discharging voltage.

Now the limit of power that can be put into an aerial is determined by the voltage at which the aerial begins to brush.

If full power is being used, the aerial is being charged up to this maximum voltage once in each train of waves only, *i.e.*, at the moments, A, A, A, in Fig. 197. It is near the maximum safe voltage for only a small part, one-sixth to one-tenth of the time occupied by a single train of waves, and hence the aerial is only radiating energy at a rate near the maximum possible for a very small proportion of the time during which the transmitting key is pressed.

If, on the other hand, some means are adopted for maintaining what is termed an "undamped oscillation," or rather a uniform high frequency alternating current (as illustrated in Fig. 198), in the aerial circuit, the aerial may be charged up to a point near its brushing voltage and will be radiating energy at its maximum rate the whole of the time during which the



*A Continuous Wave.*

FIG. 198.

transmitting key is pressed. Hence a far greater amount of power can be radiated from a given aerial for a given maximum voltage, or, conversely, for the same amount of power to be radiated from the aerial the maximum voltage can be much lower, so leading to an increased efficiency, as the aerial will have no tendency to brush.

Again, the continuous wave does not seem to suffer so much from absorption in its passage through the atmosphere between the transmitting and receiving stations.

Thirdly, selectivity in reception is much easier to obtain with the continuous wave system, for three reasons:—

(*a*) **the note is under the control of the receiving operator, as will be seen in para. 442.**

(*b*) only one wave is radiated, and

(*c*) this wave is uniform instead of being damped.

(NOTE.—The expressions "damped" and "undamped waves" are a little misleading, as of course any oscillation set up in a circuit must suffer from the damping losses due to the effective resistance of the circuit.

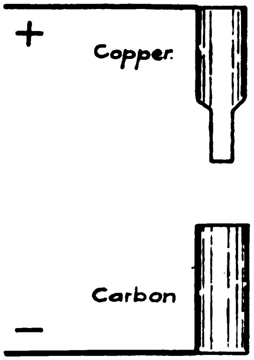
They are, however, used to distinguish the series of wave trains of decreasing amplitude produced by the spark system from the uniform continuous high frequency waves produced in the manner to be described later.)

**389. Methods of generating Continuous Waves.**—Three methods are in general use for generating a continuous high frequency oscillation in an aerial for transmitting purposes.

These are :—

(*a*) A Poulsen Arc.
(*b*) A Transmitting Valve,
(*c*) A high frequency alternator.

We will now describe the Poulsen Arc system.



*Poulsen Arc Electrodes.*
FIG. 199.

**390. The Arc.**—Suppose two electrodes, one made of copper and one of carbon, are joined to a high voltage D.C. supply, as illustrated in Fig. 199, and suppose the carbon is pushed in till it just touches the copper, then a large current will flow across their point of contact, and each electrode will tend to get intensely hot. As a matter of fact, the copper electrode is artificially cooled by means of water-cooling—otherwise it would melt—but the carbon gets white hot at its tip, and as a consequence liberates great numbers of electrons from its surface.

If now the carbon negative electrode—or cathode as it is termed—is slowly withdrawn, these electrons will fly across to the positive (copper) electrode—or anode—through the intervening air. As a result, numerous collisions between electrons and molecules of air occur, and positive and negative ions are formed.

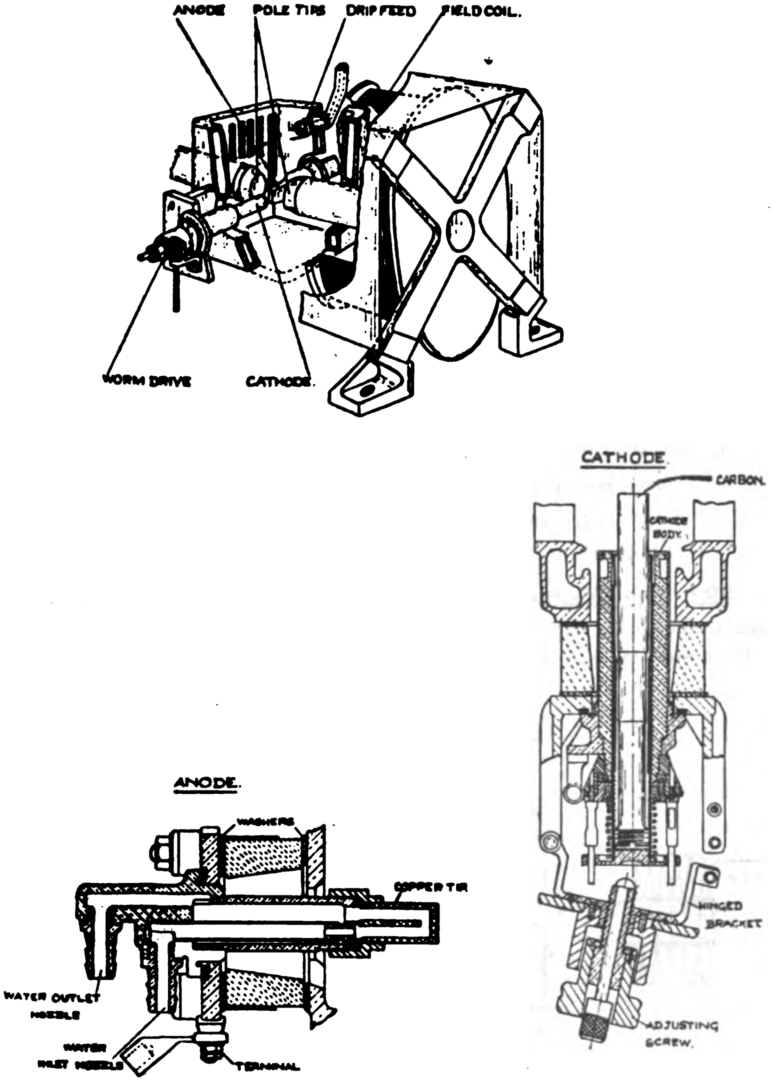


FIG. 200.

A gaseous arc is thus created which carries a convection current consisting of electrons and negative ions moving to the anode, and of positive ions moving to the cathode.

This arc can be drawn out in length until the energy supplied is insufficient to make good the energy radiated away in heat from it. It will then collapse and have to be re-struck.

**391. The Poulsen Arc.**—The arc (Fig. 200), as developed by Mr. V. Poulsen for wireless purposes, comprises a metal box, with the two electrodes projecting through its ends, and two pole tips through its sides.

The copper anode and carbon cathode are mounted in heavy porcelain insulators. The anode has internal channels drilled in it, through which water is pumped to prevent its melting. This water must be pure; otherwise it will be a conductor, and will put a dead earth on the anode.

The cathode consists of a short piece of carbon carried in a cathode sheath. This sheath is slowly rotated by means of a small auxiliary motor, driving it through intermediate worm gearing.

This ensures that the carbon burns away evenly all round, instead of only burning on one point.

The sides, and in the case of large arcs, the ends and lid, of the arc chamber are watercooled.

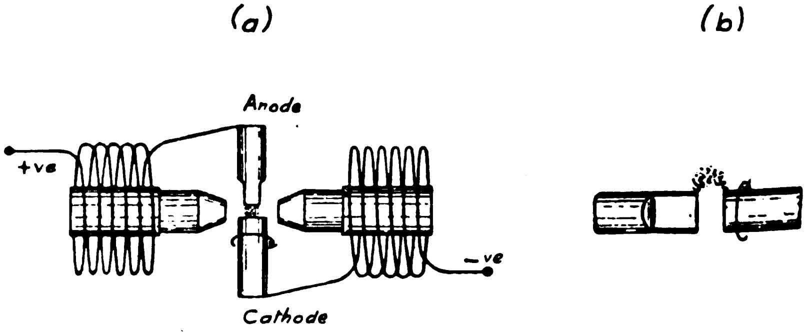
In addition to the watercooling, two other special precautions are taken to prevent the arc overheating.

These are :—

(*a*) Burning the arc in a powerful magnetic field.

(*b*) Burning the arc in a "hydro-carbon" gas, or in hydrogen gas.

**392. The Magnetic Field.**—In order to produce a strong magnetic flux across the arc, two field magnets are placed on either side of the arc, as illustrated in Fig. 201 (*a*).



*Arc Magnetic Field Circuit.*

FIG. 201.

They are wound over soft iron cores, whose tips project close to the electrodes.

The windings are joined in series with the D.C. supply mains and the arc electrodes, and thus they act also as the choking coils required to keep the D.C. supply steady (*see* para. **395**).

Consequently the arc burns in a powerful magnetic field which acts in such a direction as to bow the arc upwards (Fig. 201 (*b*) ).

(Of course, if the field coils are joined up incorrectly, the arc will be bowed downwards instead of upwards.)

Three useful purposes are served by this :—

(*a*) The arc is much longer for a given distance between the electrodes and thus has more chance of radiating its heat away.

(*b*) It is made to burn on the top edges of the electrodes, instead of being free to flicker about from point to point on them. It is thus stabilised.

(*c*) The arc length is self-regulating. When the arc current is high the field strength is great, and the arc is well bowed up. With a lower arc current the field strength decreases and so the arc length is less.

The adjustment of arc length to suit various values of arc current is thus simplified.

**393. The Hydro-Carbon Gas.**—The arc is always burnt in a "hydrogenous" vapour instead of in air. This can be produced by allowing methylated spirit to drip on to the hot carbon and become "vaporised"—or turned into gas—or by passing pure hydrogen or coal gas through the arc chamber. The first method is generally used, being simple and convenient.

The effect is that the gas, being lighter than air, conveys the heat of the arc much more quickly away to the sides of the arc chamber; in consequence of this the characteristic curve is made much steeper than when the arc is burnt in air.

The gas also helps to prevent the electrodes from becoming oxidised.

**394. Characteristic Curve of Arc.**—Such an arc as this has a peculiarity of its own—that its resistance does not remain constant, but falls off as the current through it is increased.

Consequently, the voltage drop across it decreases when the current is increased, and increases when the current is decreased.

The explanation of this rests on the fact that the resistance of the arc depends on its state of ionization, which, in its turn, depends on the heating or vapourising forces which act on the electrodes caused by the current flowing between them. The more current that passes, the more ionised vapour is available, and the more the ionised vapour the "fatter" the arc and the lower its resistance.

**If its resistance decreases fast enough,** the IR drop will decrease even when the current is increasing.

This is always the case with the Poulsen arc.

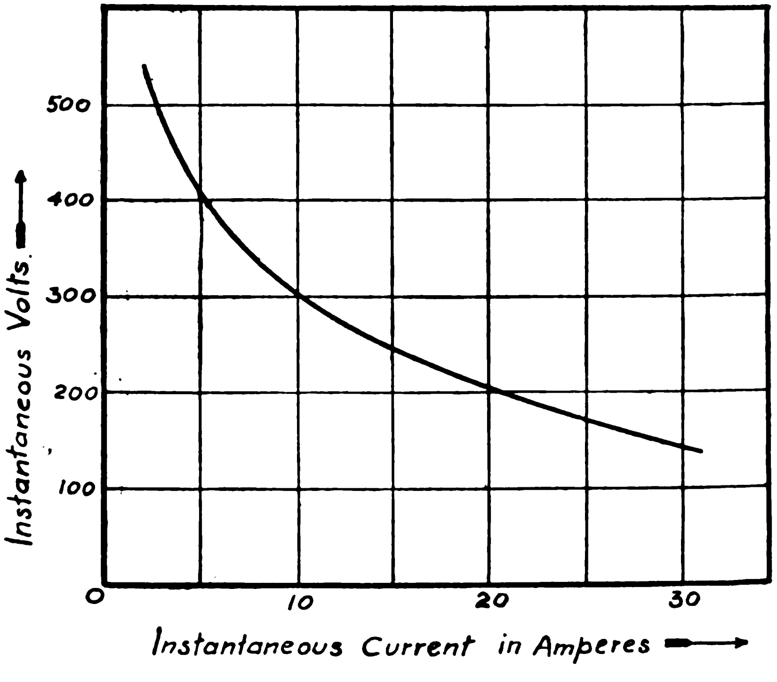
If the current through a constant resistance of 10 ohms were varied from 5 to 10 ampères, the reading of a voltmeter joined across it would increase from 50 to 100 volts.

The voltage drop across an arc varies inversely with the current as indicated by Fig. 202.

This curve is termed the "Static Volt-ampère Characteristic Curve." The name arises from the fact that it is obtained from a series of fixed static current values, together with the corresponding voltages.

It can be seen from this curve that when the current across the arc is 5 ampères, the voltage drop across it is about 400 volts; for 10 ampères the voltage drop is 300 volts; for 15 ampères the voltage drop is 240 volts.

Its resistance, therefore, varies from $\frac{400}{5} = 80$ ohms to $\frac{240}{15} = 16$ ohms for the figures taken.



*Static Volt-ampère Characteristic Curve.*

FIG. 202.

**395. Application of the Arc to an Oscillatory Circuit.**—It is on account of this peculiarity of the arc that it is suitable for maintaining an oscillation in a circuit comprising inductance and capacity.

Fig. 203 shows an arc connected to a D.C. supply through two choking coils $L_1$ and $L_2$, with a steady current flowing through the inductances and the arc, the actual value of the current depending on the arc length, the applied voltage, and the resistance of the circuit.

Now suppose an oscillatory circuit LC to be connected by means of the switch X across the arc when burning.

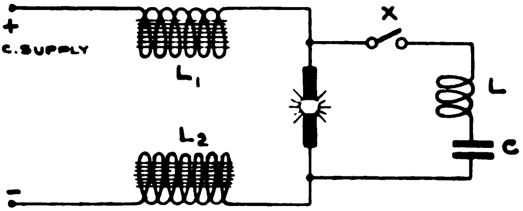


FIG 203.

Fig. 203.

The P.D. across the arc will start a current flowing into the condenser.

This current cannot come from the main supply **owing to the inductance of the choking coils;** instead the arc itself will be robbed of current. Referring to the characteristic curve, it will be seen that this will result in an increase in the P.D. across the arc, and hence a further charge into the condenser.

The voltage across the condenser eventually rises to that across the arc, but the inductance in the oscillating circuit makes the current tend to persist, and raises the condenser voltage above the arc P.D.

This voltage reaches its maximum and starts to fall as current flows out of the condenser back across the arc.

The condenser current now reinforces the arc current and, therefore, decreases the P.D. across the arc, which encourages the condenser discharge.

When the condenser voltage has reached the same value as the P.D. across the arc, the inductance comes into play again, and keeps the discharge current flowing.

This leaves the condenser with its potential less than that across the arc, so it commences to charge up again, as soon as the discharge current has ceased, and the process is continued.

In this manner the condenser current becomes oscillatory, and the oscillations will be undamped or continuous as long as the arc is kept burning. The oscillating current will reach a value depending on the electrical dimensions of the circuit, on the resistance and other losses, and on the voltage applied to the arc.

**396.** The building up of oscillations has been traced out step by step, in Fig. 204.

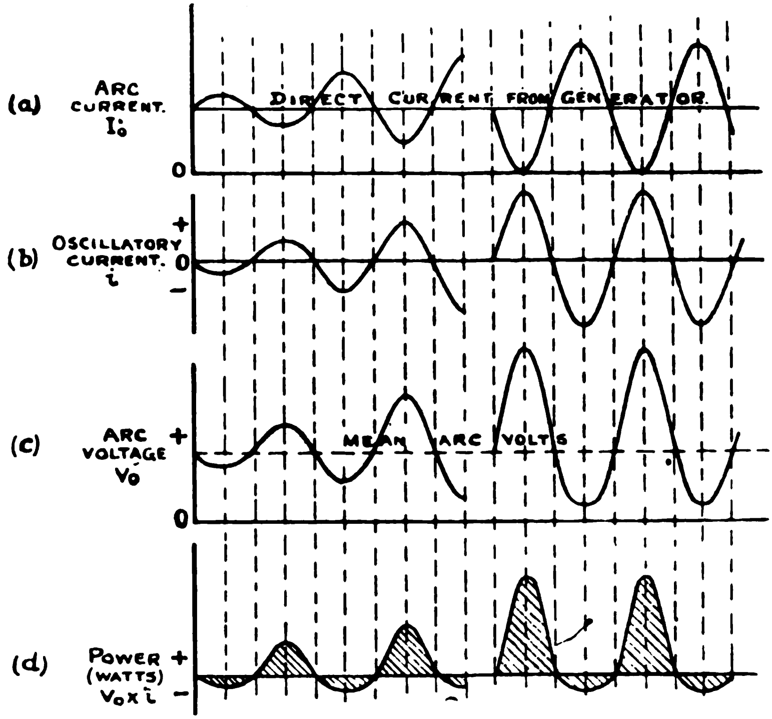


FIG. 204.

Four curves are given showing (*a*) the arc current, (*b*) the current in the oscillatory circuit, (*c*) the variations in arc voltage, and (*d*) the power delivered to, or returned by, the oscillatory circuit.

On the left the initial conditions are shown, and on the right the steady conditions when the power output of the arc is exactly balanced by the losses in the oscillatory circuit.

The curves illustrate our previous statements. When current flows into the condenser (curve (*b*) ), this comes from the arc, so the arc current falls (curve (*a*) ). When current flows out of the condenser—*i.e.*, in a negative direction—this adds to and therefore increases the arc current.

Thus the variations in arc current are exactly opposite in sense to those of the oscillatory current.

The oscillatory current rises to a maximum value which is equal to that of the direct current from the generator; for example, if the mean arc current is 10 ampères, the arc current variations (which are equal in value to the oscillatory current) would be 10 + 10 and 10 — 10.

The R.M.S. value of the oscillatory current is therefore equal to that of the direct current divided by $\sqrt{2}$: thus, if the direct current is 10 ampères, the R.M.S. value of the oscillatory current would be 7·07 ampères. (*See* para. **213**).

This is the condition that prevails when the arc length is properly adjusted.

At the moments when the arc current drops to zero, as shown in the top curve, the arc goes out, but is immediately restruck. This is the best working condition, and is arrived at by a careful design of the magnetic field strength.

If the magnetic field is too strong the arc will be extinguished too long, the oscillatory current will depart greatly from a sine curve, and the arc circuit will emit undesirable harmonics.

The variations in arc current cause variations in arc P.D. (curve (*c*) ), a rise in arc current causing a fall in arc P.D., and *vice versâ*.

It must be particularly understood that the arc voltage does not reverse in direction : it only varies above and below a certain mean value.

When it is above normal, current flows into the circuit and energy is imparted to it.

When it falls below normal, the condenser is allowed to discharge, and energy is returned by the circuit.

Curve (*d*) represents the product of arc voltage and oscillatory current. The area above the line represents energy imparted to the circuit, and the area below the line energy returned by the circuit.

It will be noticed that the energy imparted exceeds that returned.

This is on account of the peculiar behaviour of the arc. If its resistance were to remain constant, no energy would be delivered to the circuit, and the oscillation would die away.

**397. The Dynamic Characteristic.**—As a matter of fact, in practice the conditions are not quite so straightforward as those just described.

The characteristic curve of the arc on which we are working is its static characteristic.

If the curve is taken under oscillatory conditions, when it is termed a "dynamic" characteristic, it is found that the changes in arc voltage lag behind the changes in arc current.

Thus the power factor gets worse, and the energy delivered becomes less.

The lag becomes greater, the higher the frequency of the oscillatory circuit. At very high frequencies no power is delivered at all. It is found that the arc will not oscillate on waves below about 1,500 metres.

**398. Typical Poulsen Circuit.**—Fig. 205 illustrates a typical Poulsen circuit. The various items comprised in it will be discussed in detail.

**The Aerial Circuit.**—It will be noticed that there is no primary circuit used, as in the spark system, but that the arc is joined directly in series with the aerial.

Thus the length of the wave transmitted will depend solely on the capacity of the aerial and the value of the various inductances—aerial, spacing coil, variometer, &c.—joined in series with it.

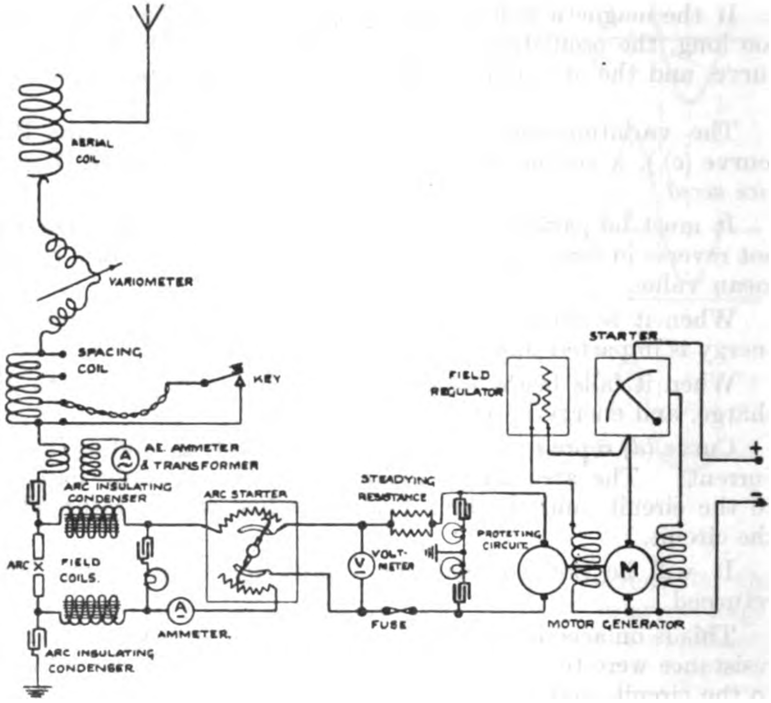


Fig. 205.

**399. Method of Signalling.**—It is not possible to make and break the charging circuit in order to signal, as is done in spark telegraphy, because the arc would go out each time the circuit was broken. Various methods of signalling are in use, one of which is termed the "Marking and Spacing Wave" method.

In this system the aerial is kept oscillating continuously, but when the key (Fig. 205) is pressed, it short-circuits a portion of the "Spacing Coil" and so alters the length of the wave radiated; therefore, one wave—termed the Spacing Wave—is being sent out when the key is open, and another (shorter) wave—termed the Marking Wave—when the key is being pressed.

If the receiving instruments of the ship receiving the message are tuned correctly to the marking wave, the spacing wave will not be heard. Owing to the selectivity of the Poulsen system a difference of 2 kilo-cycles in frequency between marking and spacing waves is quite sufficient to avoid confusion.

**Example 54.**

How much inductance is required in a spacing coil when transmitting a 150 kc. (2,000 metre) wave on a $1 \cdot 5$ jar aerial ?—

Frequency of spacing wave $= 150 - 2 = 148$ kilocycles per second.

L.C. value of marking wave $= \left(\frac{4 \cdot 8 \times 10^3}{150}\right)^2 = 1{,}024$ mic-jars.

L.C. value of spacing wave $= \left(\frac{4 \cdot 8 \times 10^3}{148}\right)^2 = 1{,}052$ mic-jars.

Inductance required in aerial for marking wave

$$= \frac{1{,}024}{1 \cdot 5} = 682 \text{ mics.}$$

Inductance required in aerial for spacing wave

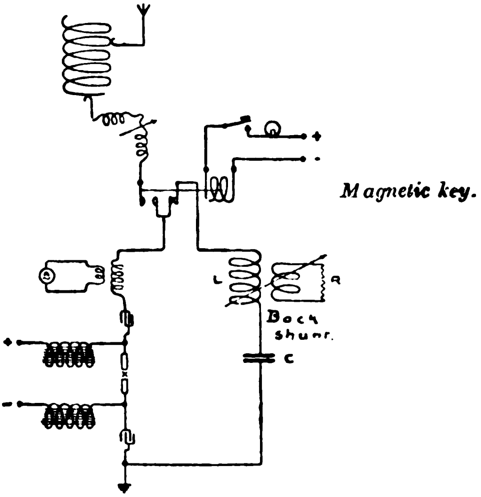
$$= \frac{1{,}052}{1 \cdot 5} = 701 \text{ mics.}$$

Hence required inductance for spacing coil

$$= 701 - 682 = 19 \text{ mics.}$$

The spacing wave radiated will be equal to

$$\frac{3 \times 10^5}{148} = 2{,}027 \text{ metres.}$$



*The Back Shunt Circuit.*

Fig. 206.

**400. The Back Shunt Circuit.**—A method of signalling which gets rid of the spacing wave is illustrated in Fig. 206. The circuit L C shown is termed a "Back Shunt" circuit. The magnetic key connects the arc alternately to the aerial and to the circuit marked LC.

When the hand key is not pressed, the right hand magnetic key contact is made, and the arc oscillates on the circuit LC.

When the hand key is pressed, the left hand spring finger of the magnetic key is pulled on to the arc contact piece, and the right hand spring finger is pulled off: the arc then sets the aerial circuit in oscillation. Thus either the aerial circuit, or the back shunt circuit, are energised according to whether the hand key is pressed or released.

In order to prevent sudden changes in the arc current, it is necessary to ensure that the effective resistance of the back shunt circuit is equal to the effective resistance of the aerial.

For this purpose the resistance R is provided, which is coupled inductively to L through a variable coupling coil.

The necessary adjustment is readily effected by varying this coupling until the current, as read on the ammeter A, is the same whether the hand key is pressed or released.

The above circuit is suitable for arcs up to about 100 kW.

**401.** The other instruments essential to the aerial circuit are shown in Fig. 205.

In order to insulate the direct current mains from the transmitting earth and from the aerial, condensers of large capacity are placed above and below the arc, as shown.

As they are of large capacity, they afford no obstacle to the oscillating current, but prevent—

(*a*) a shock from the D.C. supply being received if the aerial is touched; and

(*b*) a short-circuit if another earth occurs on the charging mains.

An accurately reading Aerial Ammeter is necessary, and is fitted as shown, across the secondary of a small "Oscillation Transformer" which is provided in order to step the aerial current down to a value suitable for passing through the ammeter.

The Variometer is provided for two purposes:—

(*a*) As a means of fine tuning.

(*b*) In order to attract the attention of the operator of the receiving ship.

It may so happen that his heterodyne circuit (*see* Chapter X., para. **443**) is set exactly in tune with the transmitted wave; he would then be on the "dead space" of the transmitting ship, and would hear nothing. The operator of the transmitting ship, therefore, before commencing his message, rotates his variometer, and thus alters his transmitted wave-length. This will cause the transmitted wave to move out of the receiving ship's "dead space," and the attention of the receiving operator will thus be attracted.

The Aerial Coil must have a large inductance, since the waves used with the Poulsen System are long ones. It must have a good current-carrying capacity, and good insulation between turn and turn.

**402. The Direct Current Circuit.**—The direct current is supplied by a motor generator or motor booster. A generator field regulator is fitted for varying the voltage applied to the arc.

A 220-volt supply may be sufficient if the insulation resistance of the aerial is high, if there are not many turns of the aerial coil in use, or if a large aerial current is not required.

If, however, the aerial is heavily damped—as it generally is in a submarine, for instance—or if a long wave is being used, necessitating the addition of a good deal of inductance (and its accompanying resistance), and if the maximum possible range—and therefore aerial current—is required, the applied voltage will have to be raised considerably.

A double-pole resistance—termed the Arc Starter—is fitted in the D.C. mains, for preventing a sudden rush of current when the arc is first struck. This resistance is gradually cut out as the arc is opened up.

A D.C. voltmeter is provided on the live side of the arc starter and a D.C. ammeter is joined in the negative main.

It should be noted than when the arc length is correctly adjusted, the reading of the aerial ammeter should be the R.M.S. value of, *i.e.*, ·7 of, the reading of the D.C. ammeter; *e.g.*, if the D.C. ammeter is reading 10 amps, the aerial ammeter should read 7 amps.

**403. Arc Main Protecting Circuit.**—It is essential to guard against the possibility of high frequency oscillations finding their way back through the charging circuit and doing damage, in the same way as in spark circuits, as described in Chapter VIII., para. **381**. This is effected by providing an easy oscillating path for the high frequency currents both close to the magnet coils and also close to the generator; for this purpose, one or more large capacity condensers and lamp resistances are provided, which afford an easier path for these currents than the high inductance of the generator armature.

(Remember, a condenser is an obstacle to direct current or low frequency alternating current, but an easy path for high frequency current, while an inductance is an obstacle to high frequency current, but an easy path to direct current or low frequency alternating current.)

**404. Adjustment of Arc Length.**—The adjustment of the arc length is dependent on the supply voltage and aerial current.

Having settled on the D.C. voltage that is to be used, the arc must be opened up until the aerial current has risen to a maximum value and is perfectly steady.

If more aerial current is required, the supply voltage should be raised, and the arc length increased.

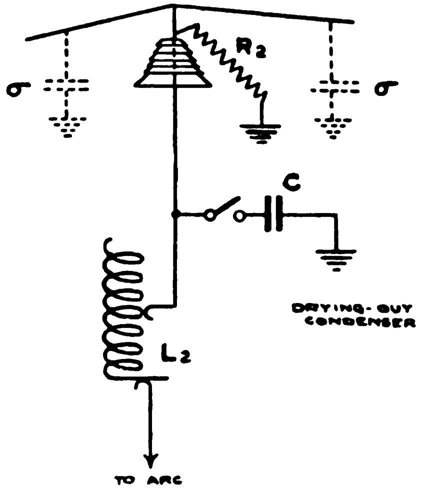
If the aerial is very efficient, the D.C. volts required will be low and the arc length will be short. Under these conditions the arc is liable to become unsteady, as it becomes excessively hot. It may even pay to put some artificial resistance in series with the aerial, increase the D.C. volts and increase the arc length.

**405. Special Conditions met with in Submarines.**—It will be of interest to describe two circuit arrangements which are used under special conditions which arise with submarines.

The first condition occurs when a submarine first rises to the surface: her deck insulator is wet with salt water, which offers an easy conductive path straight to earth, and so throws a very heavy load on the arc, which may refuse to start oscillating at all.

The second occurs when the submarine is running awash and spray is intermittently splashing on to the deck insulator. This will momentarily lower the aerial insulation resistance, and will cause violent fluctuations in the arc current, sufficient perhaps to put the arc out.

**406. The Drying-out Condenser.**—To deal with the first condition, the drying out condenser is used. With the ordinary arc circuit the voltage across the deck insulator would be very great: this voltage, being applied to the low resistance path across the damp surface of the insulator, would try to force a big current through this path: the arc would thus have a heavy load imposed on it, and would refuse to start up.

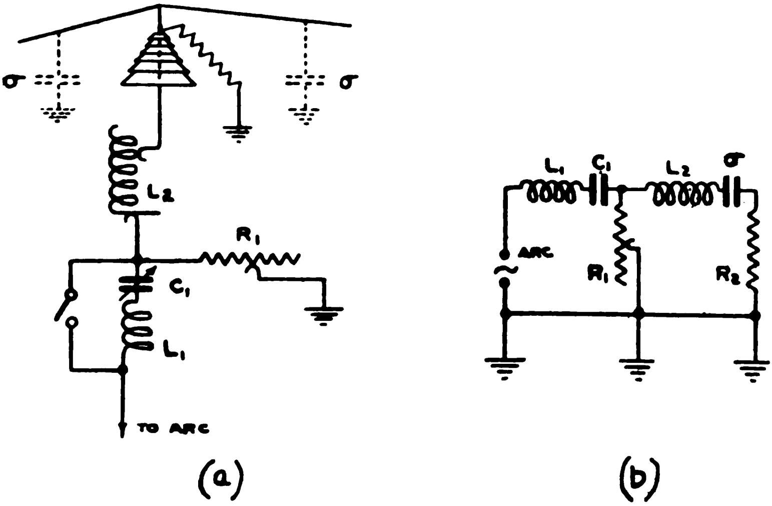


VIA VARIOMETER AND SPACING COIL.

Fig. 207.

To get over this difficulty the condenser marked C (Fig. 207) is connected up for a few minutes. It is then in parallel with the aerial capacity, and so increases the L.C. value and decreases the natural frequency of the aerial circuit. Thus the voltage across the deck insulator (= $\omega$LI volts) is decreased, the arc now has imposed on it a load with which it can easily deal, and a small oscillatory current flows over the surface of the deck insulator and quickly dries off the moisture. The condenser is then switched out, and signalling is commenced.

### 407. The Arc Steadying Circuit.



*Arc Steadying Circuit.*

Fig. 208.

The arc steadying circuit is supplied to deal with the less serious case of aerial damping when the deck insulator is being splashed intermittently.

The additional apparatus, as shown in Fig. 208 (*a*), consists of a condenser $C_1$, an inductance $L_1$, and a resistance $R_1$. The circuit $L_1$, $C_1$ is an acceptor circuit, tuned to the required wave : the circuit consisting of the aerial coil ($L_2$) and the aerial capacity ($\sigma$) is similarly tuned to the required wave.

The adjustable resistance $R_1$ is joined to earth from the mid-point of the two circuits.

Fig. 208 (*b*) shows the circuit diagrammatically. $R_2$ represents the equivalent damping effect of the faulty insulation, *i.e.*, if the aerial insulation resistance is low the equivalent damping value of $R_2$ would be great.

Now since $L_1$ $C_1$ and $L_2\sigma$ are acceptors for the same frequency, the resistance of the whole circuit will be that of $R_1$ and $R_2$ in parallel, *i.e.*, $\frac{R_1 R_2}{R_1 + R_2}$. However great $R_2$ becomes, the combined effect of these resistances will always be less than that of the smaller of the two. $R_1$ is thus the controlling factor so long as the aerial insulation is high, and, however suddenly the aerial insulation varies, the load on the arc will remain fairly constant.

The aerial circuit is coupled across the resistance $R_1$ (*vide* Ch. V., Fig. 134 (*a*) ) and so the current in the aerial will depend on the adjustment of $R_1$.

If $R_1$ is small, the arc will burn easily, but the coupling to the aerial will be loose, and not much current will flow to the aerial circuit.

If $R_1$ is increased, the coupling to the aerial, and load thrown on the arc, are both increased.

For any given condition of aerial damping the best value of $R_1$ must be found by trial.

The current in the aerial will fall off considerably whenever the aerial insulation gets very bad, so it will be necessary to repeat the message that is being made two or three times.

**408. Advantages and Disadvantages of the Arc System.**—As compared to the Spark System, the arc possesses the merits of giving greater ranges, power for power, and sharper tuning.

It is very straightforward in design, and arcs up to 1,500 kW. are in operation to-day.

The great drawback from the Naval point of view is that the arc is not suitable for quick signalling.

The arc has to be struck before signalling is commenced, and switched off again before reception—it is not possible to " listen-through " while it is burning—whereas in the spark and valve systems signals can be received whenever the transmitting key is not pressed.

This point is not of such importance in point-to-point working between shore stations, as during transmission reception may take place simultaneously on another wave and on another aerial.

## CHAPTER X.

## RECEIVING CIRCUITS.

**409.** We have seen in the preceding chapters how high frequency currents are generated in the aerial circuit of the transmitting station.

These high frequency currents set up electro-magnetic waves in the æther, which spread out radially in circles of rapidly increasing diameter from the transmitting station.

Whenever these waves encounter a conductor, and more especially an aerial, they endeavour to induce in it an oscillatory E.M.F. of the same frequency as their own.

Any station which wishes to receive a particular signal has two main objects in view :—

(*a*) To receive a signal intended for it as loudly as is comfortable to read;

(*b*) To prevent interference with this signal by other signals not intended for it.

The ordinary receiving arrangements may be summarised broadly as consisting of—

(*a*) **a circuit** which will respond most readily to waves for which it is tuned, and will not respond to waves out of tune with it

(*b*) **a detector,** for turning the wave trains into the most suitable form for energising

(*c*) some device (generally **a pair of telephones**) which will render the wave trains perceptible to the senses.

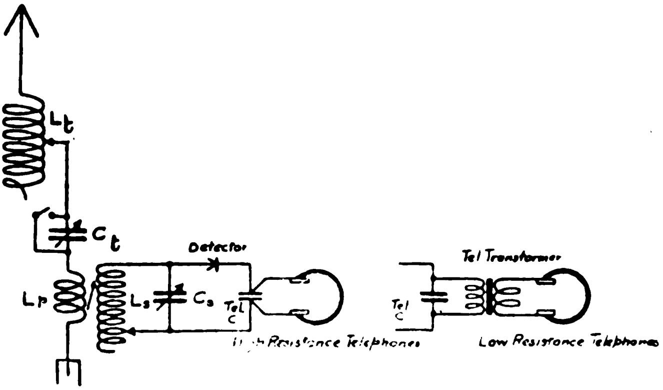


FIG. 209.

Fig. 209 illustrates a typical form of receiving circuit, which may be used in a preliminary discussion of broad principles, after which we will investigate further the various forms that receiving circuits may take.

**410. The Circuit.**—Just as in transmitting, we tuned the aerial circuit to have the same LC value as the primary circuit, in order to get the greatest possible current into it, so here we want to arrange that the LC value of the receiving aerial shall be the same as the LC value of the transmitting aerial.

We thus arrange that the natural frequency of the receiving circuit shall be the same as that of the electro-magnetic wave in the æther, and so get the greatest possible current in our circuit.

**Aerial Circuit.**—" $L_t$ " denotes the "**Aerial Tuning Inductance,**" or "Tuner," for adding inductance in series with the aerial.

" $C_t$ " denotes the "**Aerial Tuning Condenser,**" or "Aerial Condenser," for adding capacity in series with the aerial.

" $L_p$ " denotes the **primary** of an inductive coupling to the "Secondary Circuit."

It is necessary to tune this circuit so that its LC value is the same as that of the incoming wave; *i.e.*, so that it shall be a resonant circuit for this wave.

Unless the LC value of the incoming wave is the same as the LC value of the receiving aerial itself, we shall have either to add inductance in series (using the Tuner) to increase the LC value, or else capacity in series (using the aerial condenser) to decrease the LC value.

**Example 55.**

It is required to receive (*a*) a wave whose LC value is 400; (*b*) a wave whose LC value is 20, on an aerial whose natural inductance is 30 mics, and natural capacily $\sigma$ is $1{\cdot}5$ jars: the Primary ($L_p$) of the inductive coupling to the secondary circuit has a value of 40 mics.

(*a*) Total inductance required $= \dfrac{LC}{\sigma} = \dfrac{400}{1{\cdot}5} = 266{\cdot}6$ mics.

Inductance already in circuit $= 30 + 40 = 70$ mics.
Additional inductance required on Tuner $=$ **196·6 mics.**

(*b*) Total capacity required $= \dfrac{LC}{L} = \dfrac{20}{70} = \dfrac{2}{7}$ jar.

Capacity already in circuit $= 1{\cdot}5$ jars.
Additional capacity ($C_t$) must be added such that

$$\frac{1}{C_t} = \frac{1}{C} - \frac{1}{\sigma} = \frac{7}{2} - \frac{1}{1{\cdot}5} = \frac{7}{2} - \frac{2}{3} = \frac{17}{6}.$$

$$C_t = \frac{6}{17} = \boldsymbol{\cdot 35 \text{ jar.}}$$

**411. Secondary Circuit.**—A detector of any sort generally has a high resistance and, if placed directly in the aerial circuit, would cause such a damping effect that the aerial would not readily be set in oscillation by the incoming wave.

The detector is therefore preferably fed from a separate circuit of its own, inductively coupled to the aerial circuit.

This circuit is known as the " Secondary Circuit."

The inductance ($L_s$) consists of a large adjustable inductance, whose coupling to the primary can also be varied. It is arranged to have many more turns than the primary, and therefore acts in combination with the primary as a " step-up " transformer, stepping the voltage up and the current down.

Across it is joined an adjustable condenser ($C_s$) known as the " Secondary Condenser."

The secondary circuit is tuned to have the same LC value as that of the incoming wave, as is the aerial circuit.

If we wish to apply the greatest possible voltage to our detector, we shall make the secondary inductance as great as possible, and the secondary condenser as small as possible, for then the voltage across the circuit (which equals $I\sqrt{\frac{L}{C}}$ volts), will be as great as possible.

**412. The Telephones.**—For the moment we will omit further reference to the circuit, returning to it later in the chapter, and devote our attention to the other two items, viz., the **Telephones** and the **Detector.**

A pair of telephones is the device most widely used for making W/T signals perceptible to the senses. Other devices are used for automatic reception, such as a dictaphone, an inker making a mark on a piece of tape, or a moving light ray making a mark on a sensitised film; but these systems have the drawback that they cannot distinguish between the notes of various incoming signals.

The function of the telephones is to convert electric currents into an audible sound.

A telephone receiver consists essentially of an electro-magnet and a diaphragm. The diaphragm is a circular piece of very thin sheet iron, supported all round the edge by the outer case or shell of the " ear-piece " as close to the face of the magnets as possible without actually touching. Fig. 210 shows diagrammatically a section of a telephone ear-piece where " A " is the iron core of the electro-magnet, " B " the coils of the electro-magnet, " C " the case or shell, " D " the diaphragm.

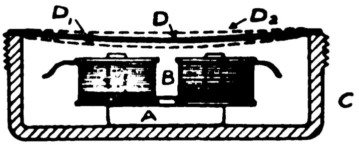


Fig. 210.

The iron core of the telephone receiver is to a certain extent permanently magnetised.

The diaphragm will therefore normally be slightly strained towards the magnet, as shown by the full line " D " in Fig. 210.

As already mentioned, it is supported by the shell of the earpiece all round the edge, but, being thin and springy, it will bulge in the middle towards the magnet.

**Action.**—The action of the telephone receiver is as follows: if a current is sent through the coils in such a direction that the lines of force assist those of the permanent magnet, the pull of the magnet will be increased, and the diaphragm will be attracted still closer to the magnet, thus taking the position shown by the dotted line " $D_1$."

If, on the other hand, a current is sent through the coil in the opposite direction, thus setting up lines of force opposing those of the permanent magnet, the pull of the magnet will be decreased, and the diaphragm will be allowed to spring further away from the pole tips and take up the position shown by the dotted line " $D_2$."

These movements of the diaphragm set up wave motions in the air, which affect the ear and produce the sensation of **Sound,** if they occur sufficiently rapidly.

The diaphragm acts in just the same way as the head of a drum, and will produce a big sound with a comparatively small displacement of its centre.

It should be particularly noted that a diaphragm can be made to vibrate equally well by either increasing or decreasing the current through the magnet windings at regular intervals.

**413. High Resistance Telephones.**—Now we remember that the magnetic effects produced by a current in a coil are proportional to the number of ampère-turns: 0·2 micro-ampère flowing through a coil of 400 turns will produce the same magnetic effect as 0·8 micro-ampère flowing through a similar coil having only 100 turns, for in each case the value of the micro-ampère turns is 80.

The resistance of most forms of detector is very high, and therefore only minute currents flow through them into the telephone receiver coils. Thus to get any appreciable magnetic effect with these small currents it is necessary to make the receiver coils with a great many turns, winding them with a great length of wire, which must be very fine in diameter to go into the small space of the receiver. In other words, the telephone coils must have a **high inductance.**

Unfortunately, a great length of fine wire means that the coils will have a high resistance, and we find that each ear-piece may have a resistance of 4,000 ohms, or 8,000 ohms for the two joined in series.

A custom has arisen of speaking of such telephones as " high resistance telephones," as if there were some merit in their being of high resistance, whereas what we really want (and use) is " high inductance " telephones.

Sometimes a pair of low inductance—or "**low resistance**"—telephones are used in combination with a **telephone transformer,** a transformer which steps voltage down and current up to a value suitable for energising the telephones.

This is indicated on the right of Fig. 209.

**414. The Necessity of a Detector.**—It has already been explained (para. 8) that wireless waves are generated in two forms—Damped Waves and Undamped Waves.

Damped Waves are generated by the Spark and interrupted continuous wave (valve) systems; Undamped Waves by the Poulsen Arc, Valve, and High Frequency Alternator systems.

Wireless waves in general consist of currents at **oscillatory (or radio) frequency,** which may be anything from 30,000 to 30,000,000 cycles per second.

It is obvious that the high inductance of the telephones will not allow the passage of current at radio-frequency, nor, if it could, would the diaphragm vibrate at such a high frequency, nor, again, could the human ear respond to such radio-frequency vibrations, as they would be above the limit of audibility.

**Audio-Frequency.**—The human ear can distinguish sounds caused by air vibrations between limits of 16 and 18,000 cycles per second, but much prefers frequencies between 800 and 3,000.

Most telephone receivers will also respond to frequencies up to 5,000 cycles, but give the best response at frequencies in the neighbourhood of 800–1,000 cycles.

In order to produce an audible sound, it is necessary—

(*a*) to **modulate** the wireless wave: *i.e.*, to break it up into a series of groups or pulses which follow one another at audio-frequency

(*b*) to **rectify** the modulated pulses, the effect of which is to turn each group of high frequency waves into a slow variation of current through the telephone windings.

In the **spark system** the wave is modulated at the transmitter, because oscillations only occur each time the spark gap breaks down; the sparking rate, or spark train frequency, depends on the alternator frequency and on the rate of revolution of the spark gap (in the case of rotating gaps). The sparking rate generally lies between 300 and 1,000 wave trains per second.

In the **I.C.W.** (interrupted continuous wave) **valve system,** the wave is again modulated at the transmitter, as explained in Chapter XIII.

In the case of **continuous** waves, whether produced by the arc, valve, or high frequency alternator system, the modulation is effected in the receiving circuit, as explained in para. **442** of this chapter.

**415. Detectors.**—In order to detect a signal, many different devices have been used. The most important, in historical order, are The Coherer, The Electrolytic Detector, The Magnetic Detector, The Crystal Detector, and the Valve Detector.

These differ widely in their appearance and nature, but all achieve the same purpose: viz., to turn a modulated wireless wave into an audio-frequency current variation through the device which renders signals perceptible to the senses.

The only two which are in use to-day are the Crystal Detector and the Valve Detector, but the latter is rapidly replacing the former for all ordinary purposes.

As, however, the crystal detector illustrates very conveniently the principle of rectification, a full description of its action will now be given.

**416. The Crystal Detector.**—A peculiar property of certain combinations of two crystals, or a crystal and a metal in contact, is that, if an alternating E.M.F. is applied to them, they (*a*) allow more current to pass in one direction than in the other, that is, they have apparently a very low resistance to currents flowing round the circuit in one direction and a very high resistance to currents flowing in the other direction; and (*b*) their conductivity varies as different voltages in the same direction are applied.

Such combinations are bornite and zincite, zincite and tellurium, or carborundum and steel, to name the ones most generally used. Many other combinations are used, but the above will serve our purpose for discussion.

Such combinations as the above are known as "Crystal Couples."

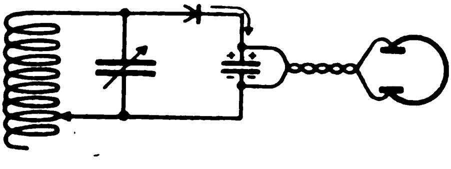


FIG. 211.

**417. Action of the Crystal Circuit.**—From Fig. 211 we see that across the secondary inductance and condenser are joined a crystal couple and a pair of telephones shunted by a condenser, known as the "Telephone Condenser." (This condenser has nothing to do with the tuning of the secondary circuit, but its duty will be made clear in the following paragraphs.)

We saw in para. **411** that an incoming wave will produce an oscillatory E.M.F. across the secondary condenser.

This E.M.F. will be applied directly across the crystal, as the telephone condenser will "pass" it easily, having a fairly large capacity, and the applied frequency being high.

(Let us assume that the crystal will pass current readily from left to right, but only a very small amount from right to left.)

During each half-cycle that voltage is applied across the crystal from left to right, current will flow through the junction and charge the upper plate of the telephone condenser positively and the lower plate negatively.

During each half-cycle that voltage is applied across the crystal from right to left, a very small current will flow through the junction from right to left and will annul only a small amount of the charge put in during the preceding half-cycle.

The nett result of a **train of waves** will be that the telephone condenser will accumulate a positive charge on its upper plate and a negative charge on its lower plate; this charge will force a current through the telephone windings and **cause a movement of the diaphragm.**

(N.B.—A telephone condenser is not absolutely essential, and is omitted in some circuits. In that case the actual self-capacity of the telephone windings performs the duty of collecting and storing the rectified impulses.)

We have thus achieved our object—to turn the train of waves into a slow rise and fall of current through the telephone windings.

The train of waves is said to have been " rectified " in passing through the crystal.

**418. The Potentiometer.**—It will here be of advantage to describe an instrument which has not been mentioned so far, but is extensively used in receiving circuits, namely, the " Potentiometer."

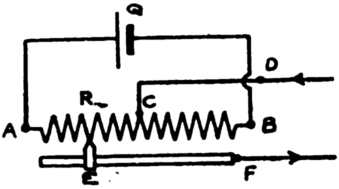


FIG. 212.

A potentiometer, as shown in Fig. 212, consists of a high resistance coil R. connected across a cell Q, and provided with two tapping points, viz., the tapping C at the middle point of the resistance, connected to terminal D, and the sliding tapping E, making contact on any point in the resistance, connected to terminal F.

The resistance of the coil should be kept sufficiently high, so that the current passing through it is not sufficient to discharge the cell rapidly. In practice a resistance of 200–300 ohms is suitable, which will allow a 2-volt cell to maintain its voltage for many weeks with continuous working.

If the voltage of the cell Q is 2 volts, then the P.D. between A and B will be 2 volts, and there will be a steady fall of potential along the whole resistance.

The P.D. between A and C, and between C and B, will be 1 volt in each case.

The P.D. between terminals F and D will depend on the relative position of the slider E to the point C.

(*a*) If E is opposite C, there will be no difference of potential between F and D.

(*b*) If E is opposite A, there will be a P.D. of 1 volt between F and D, and F will be more positive than D.

(*c*) If E is opposite B, there will again be a P.D. of 1 volt between F and D, but D will be more positive than F.

So that as E is slowly moved from A to B, the P.D. across any circuit joined between F and D will vary from a maximum in the direction F to D, down to zero, and up to a maximum in the direction D to F.

In short, a potentiometer is an arrangement for varying the strength and direction of voltage applied to any circuit joined across it.

An alternative arrangement for wiring a potentiometer, if the resistance has no centre tapping point, is shown in Fig. 213.

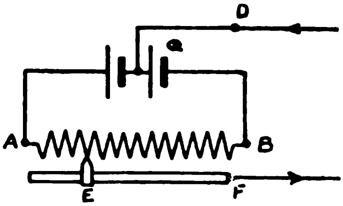


Fig. 213.

The terminal D is now joined to the centre point of the battery Q. Now the left-hand cell is trying to force a current through the resistance between A and E, and through the outside circuit in the direction of F to D.

The right-hand cell is trying to force a current through the outside circuit in the direction D to F, through the resistance E to B.

The resultant current will be the difference between the two, *i.e.*, if the resistance A to E is less than the resistance E to B, current in the outside circuit will be from F to D, and vice versâ.

**419. Characteristic Curves.**—Although the rough explanation of the action of a crystal detector given in para. **417** is perfectly true, it does not explain several points it is important we should understand.

We must investigate the action of a crystal detector more closely by considering its "characteristic curve."

First let us join up any ordinary resistance in series with an ammeter and across a potentiometer, as in Fig. 214 (*a*).

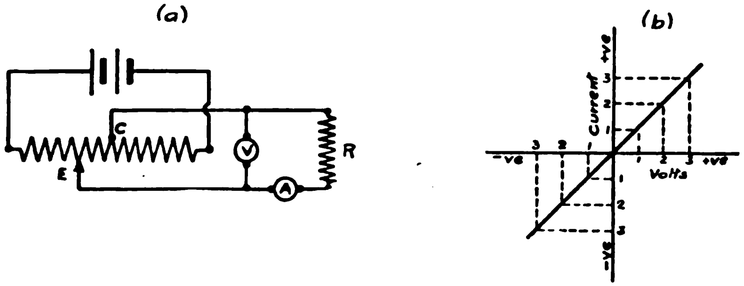


FIG. 214.

Let us term the direction from C to E. " positive " and the direction from E to C " negative."

Fig. 214 (*b*) shows current plotted against volts, which curve would be termed a " characteristic curve " of this resistance.

From it we see that when C is 1 volt positive to E, a current of 1 ampère flows from C to E through the resistance, for 2 volts 2 ampères flow, and so on.

Similarly when C is 1 volt negative to E a current of 1 ampère flows in the reverse direction, and so on.

From this we gather that the resistance R

$$= \frac{E}{I} = \frac{1}{1} = \frac{2}{2} = 1 \text{ ohm.}$$

If we replace the resistance R by a crystal couple, we get totally different curves, depending on the couple used.

Fig. 215 (*a*), (*b*) and (*c*) show characteristic curves given by bornite-zincite, tellurium-zincite, and carborundum-steel couples respectively.

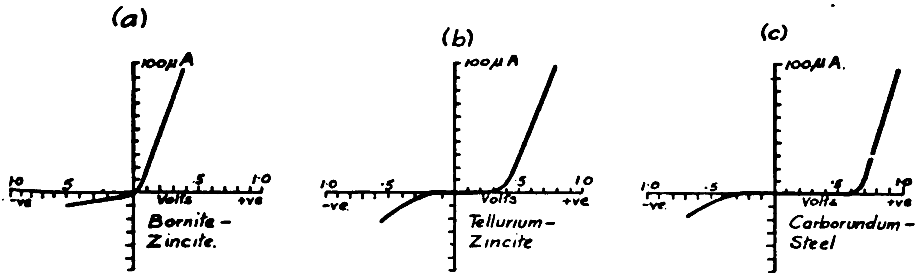


FIG. 215.

Let us refer to the direction from bornite to zincite as " positive," and that from zincite to bornite as " negative."

Fig. 215 (*a*) tells us that when voltage is applied to a **bornite-zincite couple** in a positive direction, the resistance of the crystal is low, *i.e.*, 0·1 volt gives a current of 20 micro-ampères, 0·3 volts gives 72 micro-ampères, &c.

When voltage is applied in a negative direction, the resistance of the couple increases enormously; 0·1 volt gives about 3 micro-ampères, and 0·5 volt only gives about 12 micro-ampères.

Hence the resistance of the couple to voltages applied in a positive direction is much less than its resistance to voltages applied in a negative direction.

Fig. 215 (*b*) gives a curve for **tellurium-zincite.** On the positive side no current can flow at all until 0·3 volt is applied, while after that point the current increases very rapidly for an increase in voltage.

On the negative side the resistance of the crystal is much greater, and as the voltage applied is increased, the increase of current is much slower.

The characteristic curve for **carborundum-steel** (*c*) is very similar, except that the critical point at which the curve bends sharply upwards is when about 0·7 volts is applied instead of 0·3 volt, as in the case of the tellurium-zincite detector.

**420.** Let us now consider what happens when we join up a bornite-zincite couple in the secondary circuit as shown in Fig. 211.

An incoming wave train will set up an oscillation in the secondary circuit, which will apply an oscillatory E.M.F. directly across the crystal, as shown in Fig. 216 at (*a*).

It is important to notice the manner in which Fig. 216 is drawn.

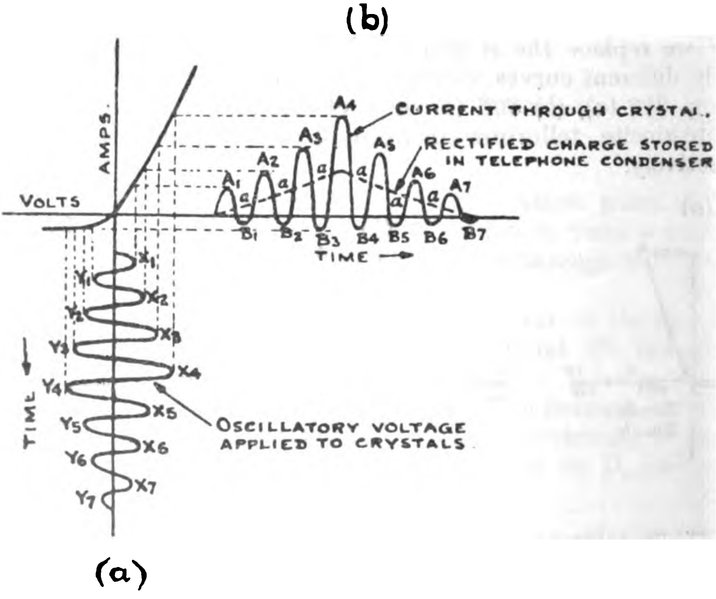


FIG. 216.

Fig. 216 (*a*) shows a characteristic volt-ampère curve of a crystal, with the voltage of a damped wave train being applied, By running perpendiculars from the oscillatory-voltage curve to cut the volt-ampère curve, the corresponding current can be determined.

Fig. 216 (*b*) shows the resulting rectified current plotted against time, and the **area** enclosed by the curve above or below the line indicates I × t or coulombs flowing into the telephone condenser.

Now during the positive half-cycle of voltage $X_1$, a current will flow through the crystal from left to right (Fig. 211), and will introduce the positive charge into the upper plate of the telephone condenser as indicated by the area $A_1$, Fig. 216 (*b*).

During the next half-cycle of voltage $Y_1$, the negative charge $B_1$ will be introduced into the telephone condenser, and will annul a **small** amount of the charge introduced by the preceding half-cycle of voltage.

As the area $A_1$ is considerably greater than the area $B_1$, the result of the cycle of applied voltage $X_1Y_1$ will be the **introduction of a charge** into the telephone condenser equal to the difference between the areas $A_1$ and $B_1$.

The same result will occur at each succeeding cycle of the voltage applied, with the result that a charge will have accumulated in the telephone condenser at the end of the wave train equal to the difference between the total area enclosed by the curve above the line and the total area enclosed by the curve below the line.

This is indicated by the area below the dotted line **a a a**, which indicates the total rectification during the wave-train.

The charge introduced into the telephone condenser will set up a certain P.D. across it, which will force a certain direct current through the telephone windings depending on their resistance and inductance.

Hence each wave train sets up a unidirectional rise and fall of current through the telephones, the diaphragms of which will consequently be attracted and released once for each wave train.

**421.** It will be noticed that the current in the detector circuit has both a radio-frequency variation and an audio-frequency variation.

It is convenient to consider it as made up of an audio-frequency current superimposed on a radio-frequency current.

The telephone condenser offers a low-impedance path for the radio-frequency component, while the audio-frequency current passes readily through the telephone windings and operates the telephone diaphragm, causing a sound wave.

**422. Rectification with Tellurium-Zincite.**—Now, although **bornite-zincite** makes a sensitive detector, the contact must be a very delicate one, accurately adjusted, and is rather liable to be thrown off by gunfire, by heavy atmospherics, or by a ship transmitting near by on full power.

The other two couples mentioned—tellurium-zincite and carborundum-steel—provide a rather more robust arrangement.

If, however, we merely put them in the circuit in place of the bornite-zincite, the result will be very disappointing.

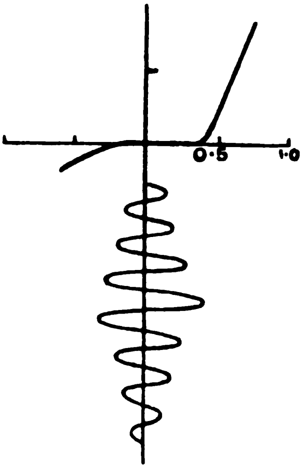


FIG. 217.

Fig. 217 shows the oscillatory voltage of a wave train as applied to the characteristic curve of a tellurium-zincite couple. It can be seen that unless the voltage applied is greater than ·3 volt, no current flows at all. The same negative result would occur with a carborundum-steel couple.

In each case, unless the oscillatory voltage applied is a large value, it is insufficient to force any current through the high resistance contact.

This is where the potentiometer comes in.

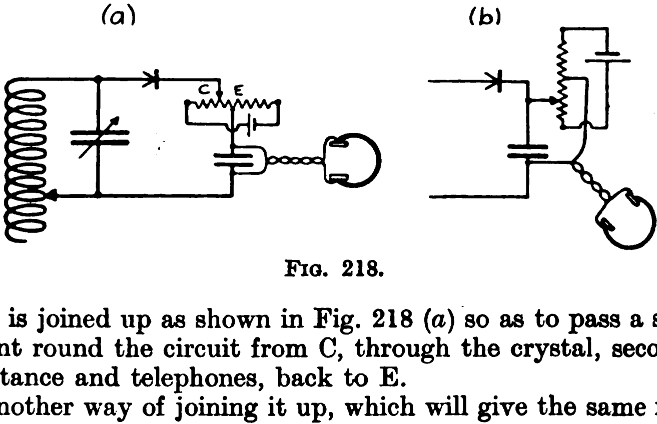


FIG. 218.

It is joined up as shown in Fig. 218 (*a*) so as to pass a steady current round the circuit from C, through the crystal, secondary inductance and telephones, back to E.

Another way of joining it up, which will give the same result, is shown in Fig. 218 (*b*).

This latter arrangement has the advantage that the **oscillatory** currents need not pass through the resistance of the potentiometer, but as this resistance is comparatively small compared to that of the crystal, the advantage gained is unimportant.

There are now two voltages acting on the crystal :—

(*a*) The steady voltage of the potentiometer,
(*b*) The oscillating voltage of the incoming wave.

The current that flows through the junction will be that due to the resultant of these two.

Let us apply a steady positive voltage from the potentiometer equal to that at which the curve turns up sharply (at the point X), *i.e.*, ·35 volt (Fig. 219).

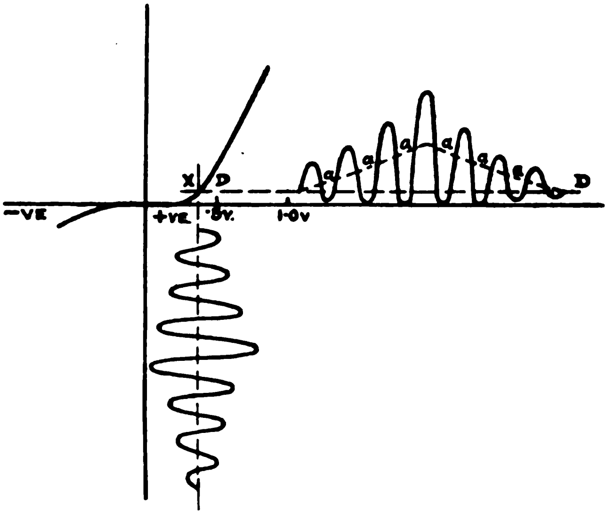


FIG. 219.

Then a steady current will flow through the telephones as shown by the line DD.

When an oscillatory E.M.F. is applied, a positive half-cycle will act in the **same direction** as the potentiometer voltage, and a negative half-cycle **in opposition** to it.

The resulting charges put in to the telephone condenser will be, as before, the charges put in during positive half-cycles less the charges put in during negative cycles.

The area enclosed below the line " a a a " indicates the total rectification during the train of waves, *i.e.*, the charge in the telephone condenser that will move the telephone diaphragm.

The telephone diaphragm will be deflected by an amount proportional to the difference between the steady current DD, which is due to the potentiometer voltage only, and the current a a a, which is due to the combined effects of the potentiometer voltage and the crystal rectification.

The same argument applied to the carborundum-steel curve will give a similar result.

We see, therefore, that by means of a potentiometer we get the crystal into the most sensitive condition for reception by making use of the sharp bend of its characteristic curve.

In short, the duty of the potentiometer is to heat up the junction of the crystal couple to the point where the latter suddenly becomes unidirectionally conductive.

An ideal characteristic curve is one that turns up very steeply on one side of the line of origin, and is as flat as possible on the other side, for then the resulting rectification will be as great as possible.

A very convenient way of regarding the application of the potentiometer is to think of it as a means of sliding the axis of the ordinates to the right or left at will, so that it cuts the characteristic curve at the point where it bends most sharply.

For instance, the curve of Fig. 220 (*a*) with a potentiometer adjusted to point X is the same as the curve of Fig. 220 (*b*).

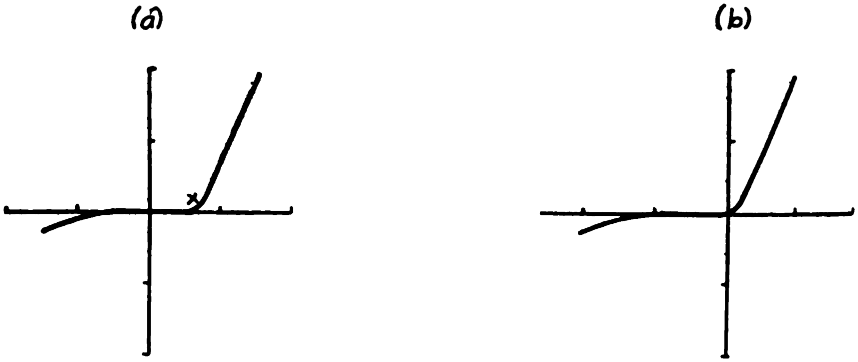


FIG. 220.

We have not yet seen any reason why the potentiometer voltage should be made reversible.

This is because apparently similar crystal couples have very different characteristics.

One crystal may have a characteristic as in Fig. 221 (*a*), steepest on the positive side, *i.e.*, from carborundum to steel,

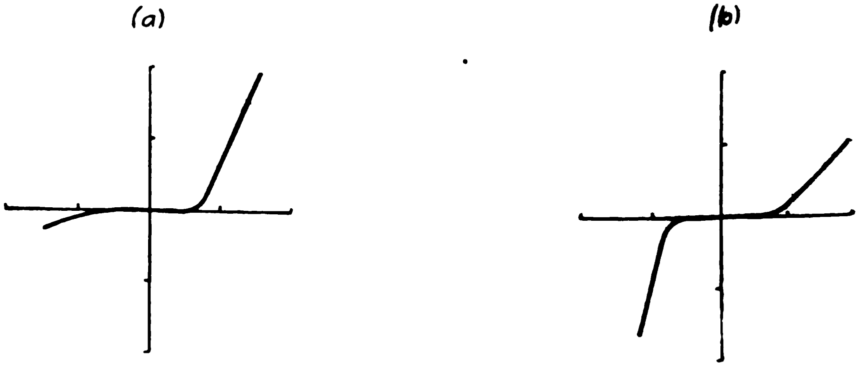


FIG. 221.

and another as in Fig. 221 (*b*), steepest on the negative side, steel to carborundum.

For (*a*) we should apply the voltage in a positive direction, and for (*b*) in a negative direction.

The potentiometer slider should always be moved slowly in each direction until a point is found which gives the loudest signals.

(The same result is obtained in some receiving sets by turning the crystal couple round in its holder instead of reversing the voltage.)

**423.** The actions described in the preceding paragraphs may be summarised thus, Fig. 222 :—

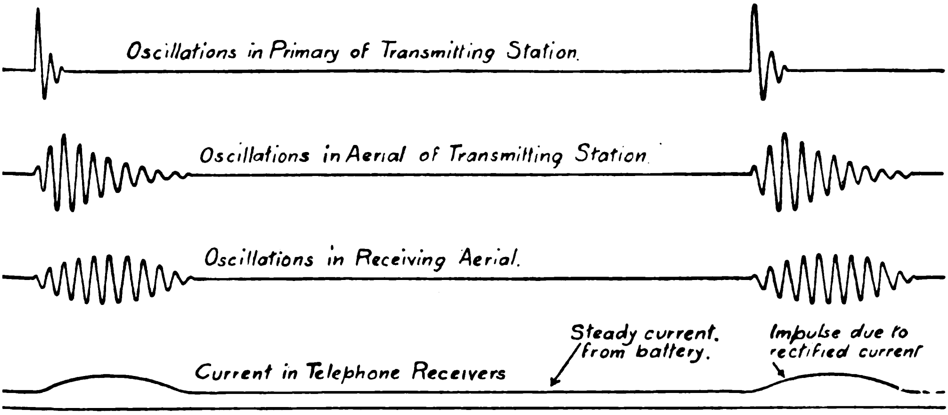

Oscillations in Primary of Transmitting Station.
Oscillations in Aerial of Transmitting Station
Oscillations in Receiving Aerial.
Steady current. from battery.
Impulse due to rectified current
Current in Telephone Receivers

Fig. 222.

**424. Receiving Circuit Arrangements.**—We can now return to the question of receiving circuits, and consider them more carefully.

The outstanding difficulty met with in the design of receiving circuits is that of avoiding interference, whether from atmospherics (para. **438**) or from signals which we do not wish to receive.

With the help of amplifiers (described in Ch. XII) it is possible to bring up any signal, however weak, to audible strength, but it is extremely difficult to prevent this signal being blurred by the interference referred to above.

**425. Tuning the Aerial Circuit.**—It has been explained in para. **410**, that the aerial is tuned to waves longer than the natural wavelength by the use of the aerial tuning inductance, and to those shorter by means of the aerial tuning condenser.

When receiving very long waves it is sometimes inconvenient to use more than a certain amount of inductance in series; then the arrangement shown in Fig. 223 may be employed. It will be seen that by means of a double pole two-way switch the aerial tuning condenser (A.T.C.) may be put in series or in parallel with the aerial tuning inductance (A.T.I.).

When **in series,** the A.T.C. reduces the wavelength of the circuit in the usual manner.

When **in parallel,** a closed oscillatory circuit is formed, with which the aerial circuit is in series. In this position an increase of either the A.T.I. or of the A.T.C. will increase the wavelength of the circuit.

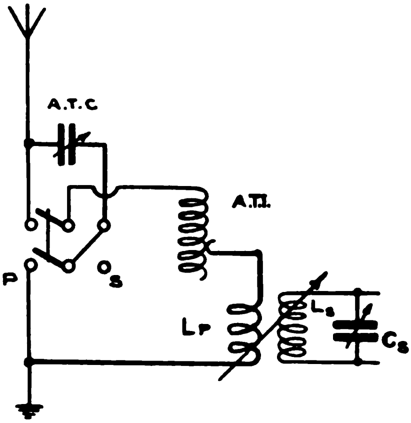


FIG. 223.

The L.C. value of this circuit will be (A.T.C. + $\sigma$) × (A.T.I. + $L_P$).

In order to keep down the resistance of the circuits, a small value of the A.T.I. should be used.

**426.** It should be remembered that in most Service receiving sets the incoming wave has first to pass through the aerial circuit of the transmitting system, as illustrated in Fig. 224,

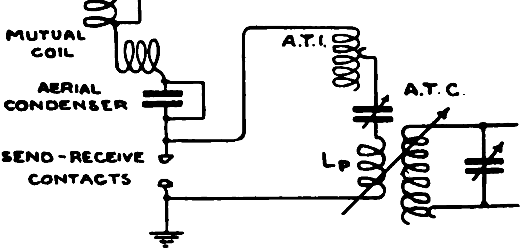


FIG. 224.

which shows the receiving circuit added on to the spark aerial circuit given in Chapter VIII., Fig. 196.

Similar arrangements are made in arc and valve circuits.

If reception is taking place on the wave which the aerial is tuned to transmit, a very small adjustment of the A.T.C. only (to compensate for the inductance of $L_1$, the inductive coupling to the detector circuit) will suffice, without the need of any additional inductance on the A.T.I.

**427. Direct Coupled Receiver.**—The simplest form of receiving circuit is shown in Fig. 225. The detector circuit is fed directly off the aerial tuning inductance. This circuit is extremely easy to handle and gives strong signals, but it is so susceptible to all forms of interference that it is only used in cheap and crude receiving sets.

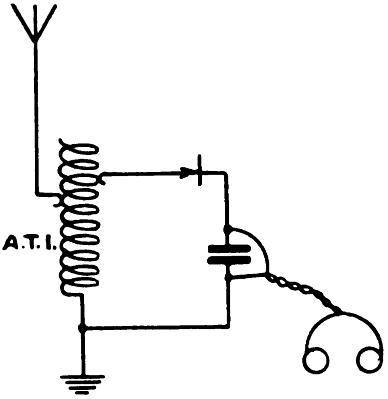


FIG. 225.

**428. Selectivity.**—The object aimed at by designers of all modern receiving gear is to obtain "selectivity"; that is, so to arrange their circuits that they will not respond to waves which are not in resonance with them, and are influenced as little as possible by atmospheric interference.

The methods employed fall under three headings :—

(*a*) The use of stiff acceptor circuits.

(*b*) The use of rejector circuits.

(*c*) The use of loose couplings.

The principles of acceptor and rejector circuits have been fully described in Chapter V.

To recapitulate them briefly :—

(*a*) **An acceptor circuit** is an easy path for the wave to which it is tuned, and a difficult path for all other waves (para. **242**).

(*b*) The greater the ratio of inductance to capacity the more difficult a path is it for interfering waves (para. **242**).

(*c*) Two or more acceptor circuits may be joined in series without altering the tuning of the circuit as a whole. The advantage gained is an increase in the ratio L/C (para. **243**).

(*d*) **A Rejector circuit** is opposite to an acceptor circuit in its effects. It is an easy path to all waves except the one for which it is tuned; to this one it offers an impedance which is greater the lower its resistance losses (para. **257**).

(*e*) The greater the ratio of C/L, the easier path does the circuit offer to non-resonant frequencies (para. **257**).

**429.** Some different circuit arrangements are shown in Fig. 226.

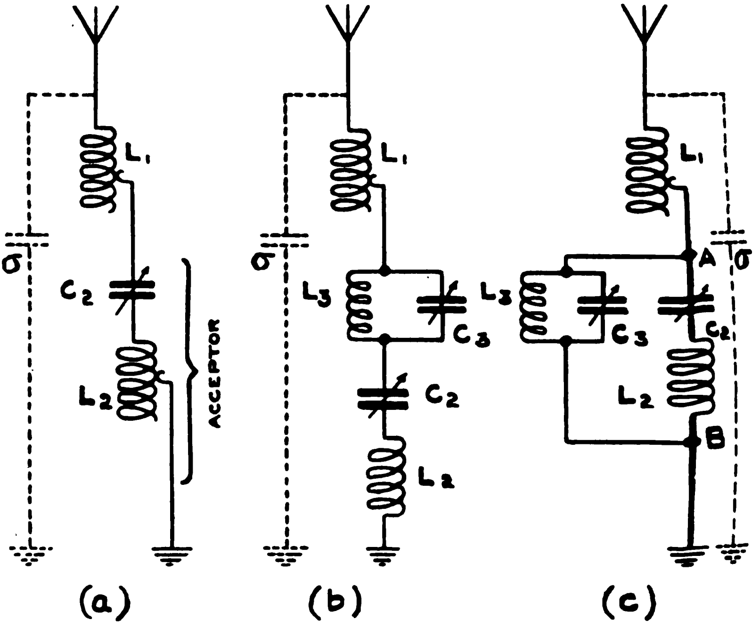


FIG. 226.

Fig. 226 (*a*) shows two acceptor circuits in series. $L_1$ is the aerial tuning inductance which, in combination with the aerial capacity $\sigma$ (shown dotted), is in resonance with the incoming wave.

The circuit $L_2$ $C_2$ is separately tuned to the same LC value as the circuit $L_1$ $\sigma$.

The circuit then, as was shown in para. **243**, is correctly tuned as a whole.

The merit of this arrangement is that $L_2$ can be increased and $C_2$ diminished, at will, to make the lower circuit as stiff as may be required.

The inductance $L_2$ may conveniently be used as the primary of the inductive coupling to the secondary circuit.

**430.** Fig. 226 (*b*) shows a rejector circuit $L_3 C_3$ joined in series with the aerial to bar some particular interfering wave.

The circuits $L_1 \sigma$ and $L_2 C_2$ are tuned to the wave required, **whereas $L_3 C_3$ is tuned to the interfering wave** and bars its passage, while permitting the required wave, for which it is not tuned, to pass easily.

**431. Acceptor-Rejector Circuit.**—Fig. 226 (*c*) shows a rejector circuit shunted across an acceptor circuit, to act as a by-pass for all interfering waves.

**All three circuits are tuned to the same LC value.**

Let us consider how this circuit will behave with regard to the resonant wave, and to interfering waves.

**The Resonant Wave.**—The only oscillatory voltage required between A and B to maintain the oscillatory current is that necessary to overcome the effective resistance of the acceptor and secondary circuits combined. That is to say, A is a point in the aerial circuit which is very nearly at earth potential (para. **245**).

Thus there is only a very small voltage acting across the rejector, which will only cause a negligible current to flow through it, provided that its resistance is low.

**Action of Circuit on Interfering Waves.**—Now consider the action of the circuit when waves of other frequencies strike the aerial.

If these waves are sufficiently powerful, as is the case with a station transmitting on full power a few miles away, then some current of the interfering frequency is set up in the aerial circuit.

This current has two paths to earth :—

(*a*) Through the rejector circuit.

(*b*) Through the acceptor circuit.

Consider (*a*) first. Since the frequency of the interference is different to that for which the rejector is tuned, it follows that a large amount will flow through the rejector for a small applied voltage. This current has no direct influence on the secondary circuits and will not lead to signals in the telephones.

Now consider (*b*). The acceptor circuit is not in tune to this interference, and consequently relatively large voltages will be required to cause any appreciable current to flow.

But no large voltages are available, because even large aerial currents due to the powerful waves can get away to earth through the rejector with quite small voltages across it.

Moreover, the interfering current has to pass first through the aerial circuit, which is a stiffly tuned acceptor, and will be considerably cut down in its passage.

The action of the acceptor and rejector circuits with interference is thus exactly the reverse of their action with the waves to which the circuits are tuned.

In the first case the rejector acts as a by-pass to earth for practically all the aerial current of the interfering frequency, and the acceptor, being out of tune, carries practically none of the current.

But in the second case, with the in-tune oscillations, the rejector becomes a non-conducting path and the acceptor a conducting path, with the result that practically all the current passes through the acceptor and none is wasted through the rejector.

**432. Drain Circuit.**—If interference from any one particular wave is experienced, it may be minimised by fitting a "drain" circuit for it.

Fig. 227 illustrates a receiving set tuned to receive a 400-metre wave, with a circuit tuned to be an acceptor for a 100-metre wave tapped off from a low potential point.

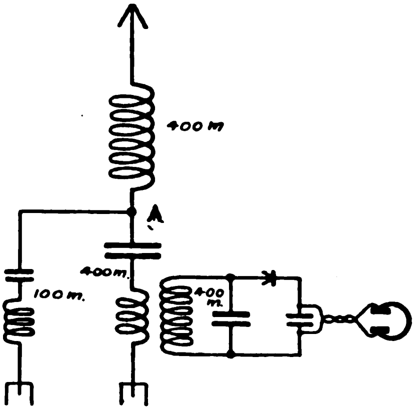


FIG. 227.

The 400-metre wave will set in oscillation the various circuits tuned to its frequency, while it will waste very little of its energy on the 100-metre circuit.

The interfering 100-metre wave will expend whatever energy it has left at the point A in setting up an oscillation in the drain circuit which is tuned to it, and should cause no interference in the telephone.

**433. Coupling.**—Selectivity may also be obtained by means of the coupling between the aerial and secondary circuits.

If this coupling is fairly tight, the aerial can set the secondary circuit in oscillation easily, and can supply its energy to the detector at a convenient rate for the latter to deal with it.

If the coupling is loosened, it becomes much harder for interfering waves to set the secondary circuit in oscillation.

If the coupling is made much too loose, the required signals become so weak as to be unreadable, and the greater part of the absorbed energy is wasted in $I_2R$ losses. The aerial is unable to hand over to the detector all the energy it absorbs from the æther wave, and a certain amount is re-radiated into the æther again.

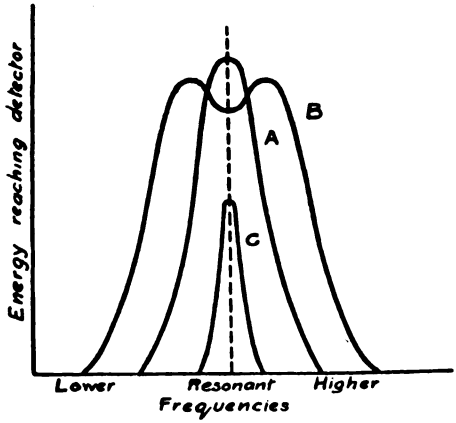
If the coupling is made too tight two ill effects occur :—

(*a*) The tight coupling of the detector circuit to the aerial damps the latter so heavily that incoming waves find it very difficult to set up oscillations at all.

(*b*) A double frequency, or two-wave, effect, is set up, as in a tightly coupled transmitting circuit, and the incoming wave is cut down.

This may be an advantage in receiving signals from a station using a tightly coupled transmitter; it may be possible so to adjust the coupling of the receiver that the receiving circuit picks up both the transmitted long and short waves equally well.

As a general rule, however, it will be found that there is one degree of coupling which gives loudest signals. An increase or decrease of coupling from this point weakens signals, although the decrease of coupling may give an increase of selectivity.



Curve A : best coupling for strongest signals.
Curve B : too tight coupling.
Curve C : loose coupling.

FIG. 228.

These three effects are illustrated in Fig. 228.

Curve A illustrates what occurs with the coupling that gives loudest signals. A maximum of energy reaches the detector at the resonant frequency, but interference of lower or higher frequency is cut down.

Curve B shows what happens when the coupling is made so tight that a double frequency effect is set up.

The proper resonant wave is cut down, while bad interference is brought in from waves a little lower or higher in frequency than the resonant one.

Curve C shows the effect of too loose a coupling. Selectivity is very good—*i.e.*, very little energy reaches the detector at non-resonant frequencies—but the resonant wave is also very much weakened.

**434. Adjustment of Secondary Circuit.**—The Secondary Circuit comprises the secondary condenser and the secondary inductance, which has a variable coupling to the aerial circuit.

As regards the ratio $\frac{L}{C}$ :—

For maximum strength of signals, the secondary inductance should be big and the secondary condenser capacity small, for then the step-up in voltage is as great as possible, and the maximum voltage is applied across the condenser to the crystal.

For maximum selectivity, the secondary inductance should be decreased and the secondary condenser increased, for then the step-up of the transformer is decreased, and also the peak voltages across the inductance and capacity of this resonant circuit are decreased; the result will be that the voltage applied to the detector by both resonant and interfering waves will be decreased, and if the resonant frequency wave is strong we can afford to weaken it a bit if we cut down the interference thereby.

Although the secondary circuit consists of an inductance and capacity in parallel, it cannot be regarded as functioning as a true rejector circuit. This is because energy is supplied to it by magnetic coupling through the inductance, and not directly at the mid-points between the condenser and inductance; consequently the balancing out of resonant currents through the two parallel paths does not take place as in a true rejector. Moreover, the high resistance of the detector circuit is shunted across it, so energy is continually being abstracted.

### 435. Capacity Coupling.

A type of coupling known as "Capacity Coupling" is illustrated in Fig. 229.

The secondary circuit $L_2C_2$ is coupled to the inductance $L_1$ in the aerial circuit, through the condenser $C'$.

As the capacity of $C'$ is varied, so the closeness of coupling between the aerial and secondary circuits is varied.

The greater $C'$ is made, the more nearly it approximates to a short-circuit, and therefore to a direct coupling.

The smaller it is made, the more nearly it approximates to a dead break, or zero coupling.

Hence the variation of $C'$ affords a very delicate adjustment of coupling, provided that $L_2$ is so screened from $L_1$ that there is no mutual inductance between them.

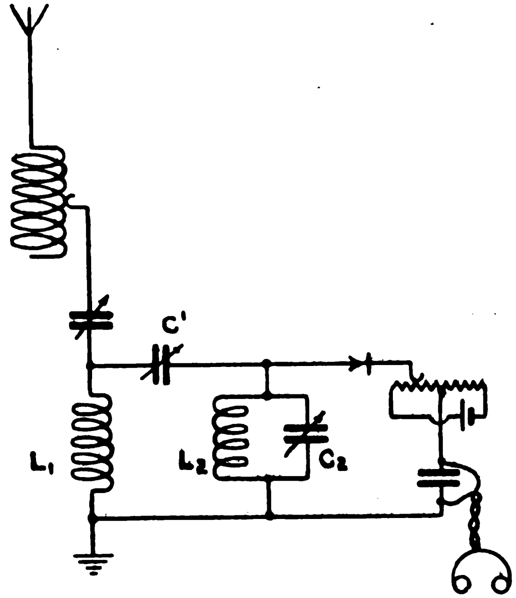


FIG. 229.

The circuit $L_2C_2$ acts as a rejector, and helps to shunt interfering currents from the detector circuit, without weakening the resonant wave.

**436. Tuning Receiving Gear.**—As a general principle, a list of receiving adjustments for all waves should be available in the silent cabinet.

When first picking up a wave whose correct adjustments are not known, the whole circuit should be made as unselective as possible; that is, all series acceptor circuits should have small inductance and large capacity, the coupling to the secondary circuit should be tight, and the secondary inductance should be big and the secondary condenser small.

When the wave has been picked up it is advisable to get two sets of adjustments: one, fairly unselective, for use when signals are weak, and one, as selective as possible, for use when signals are strong and interference is bad.

**437. Shock Interference.**—All the preceding arguments have been based on the ordinary theory of alternating currents, as if we merely had to consider the effects of regular alternating currents of different frequencies applied between aerial and earth.

With continuous wave valve transmitters we do get these conditions very nearly, and to a certain extent with arc transmitters, but with spark systems we have to deal with damped trains of waves, often starting with a very big initial amplitude if the transmitting station is close to the receiving station and is using a tight coupling.

When such waves strike an aerial which is not tuned to their frequency, although they are quickly damped out of it, they are able to expend a certain amount of their energy in setting it oscillating at its own natural frequency by pure shock in the same way as a bell is set ringing when struck with a hammer.

Such interference cannot be cut out by any amount of selective tuning, and the only way for the operator to deal with it is to " over-read " the note of the signal he wishes to receive.

**438. Receiving through Atmospherics.**—" Atmospherics " are a source of interference universally experienced. They are the result of electric waves set up in the æther by an electric disturbance of some sort, such as flashes of lightning in a thunderstorm, but the source of origin may be at a great distance from the receiving station (*see also* Ch. XV.).

Various elaborate circuits have been tried for reducing them, but generally without much success, as they are a form of shock interference of no particular frequency, and merely set the aerial in oscillation at **its own** natural frequency.

The best way of dealing with them may perhaps be to use some " limiting " device, such as a " limiting " valve (described in Chapter XII.) the object of which is to prevent any incoming signals or atmospherics, however strong, from giving more than a certain maximum sound in the telephones. As the atmospherics can be no louder than the required signal, the operator is given a chance of over-reading the musical note of the signal.

**Statics.**—Another form of atmospheric trouble that sometimes arises is that known as " Statics." These are stray electrical charges that are picked up by the aerial, and if the latter happens to be left insulated by, for instance, an aerial condenser, these charges will accumulate, and will eventually break down the insulation of the condenser and spark through it.

A coil known as an " Aerial Discharge Coil," having very high resistance and inductance, is frequently connected across the receiving gear to earth.

None of the incoming wave passes through it, on account of its high impedance, but it allows static charges to leak slowly through it to earth.

Inductances and condensers are often protected from lightning by joining " safety points " or " lightning arresters " across them.

**439. Wiring of Receiving Circuit.**—In wiring receiving gear, we have two important losses to guard against :—

(*a*) $I_2R$ or ohmic losses in conductors.
(*b*) Leakage losses through bad insulation.

Now, naturally, wherever we have a **large current** we shall have to be specially careful to provide a good conductive path.

This will be the case in all circuits which have large capacity and small inductance.

In all such circuits, therefore, it is important to provide low resistance conductors of good surface area.

Whenever we have a **big voltage** we shall have to be specially careful to provide very good insulation.

There will be very big voltages to earth at the high potential points of all circuits having a large ratio of inductance to capacity.

A very good test to find the high potential points (paras. **244** and **245**) of a receiving circuit is to see whether signals disappear when any particular point is touched with the finger.

All leads should be as short, direct, and non-inductive as possible; it is not a good thing, however, to run two leads side by side with the idea of making them non-inductive, as they will have a considerable capacity between them, which will make tuning to short waves difficult.

It is particularly important to see that the receiving earth is good. This matter is discussed in Chapter XVI.

**440. Reception of Continuous Waves.**—The reception of continuous waves differs from the reception of damped waves, for the latter arrive in the aerial one train at a time, separated by comparatively long periods; this allows the telephone condenser to discharge through the telephones during each train, and the telephone thus appreciates a change of current for each train of waves; as these follow one another at regular intervals a sound is heard in the telephones as a note corresponding to the modulation frequency of the transmitting station.

Now with continuous wave transmission the waves do not occur in separate trains, but as one continuous train during the whole time the key of the transmitting station is pressed.

Therefore, in order that the telephone may appreciate the passing of one long train of oscillations, it is necessary to break up that long train into groups, succeeding one another at intervals corresponding to an audible frequency; the telephone will then respond audibly to the current due to each group if these are rectified by a suitable detector and if these groups follow one another at regular intervals.

There are several methods of obtaining this desired result :—

(*a*) At the sending station the aerial current may be interrupted or varied at intervals corresponding to an audible frequency. A device for effecting this is called a "Tone Wheel."

(*b*) At the receiving station the current in the detector circuit may be interrupted or varied at audible frequency. An arrangement for doing this is called a "Ticker," and is generally either an arrangement for breaking and making the circuit, or altering the capacity, inductance or coupling, by breaking or making an additional circuit or rotating a closed coil near one of the coils in the circuit.

Neither of these two methods gives such satisfactory results as :—

(c) Heterodyne reception

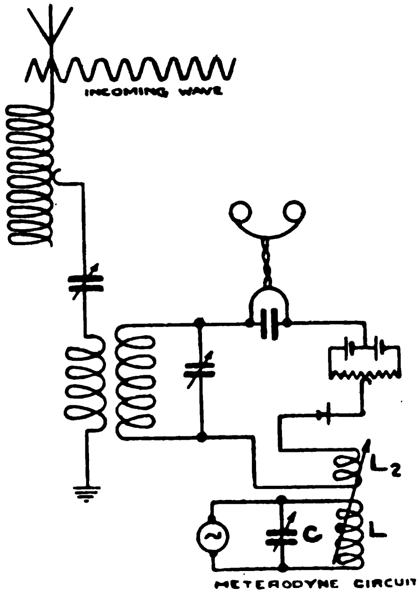


FIG. 230.

**441. Heterodyne Reception.**—In the heterodyne system of reception a separate circuit—known as the " heterodyne circuit " —is coupled loosely to the detector circuit, as illustrated in Fig. 230. The heterodyne circuit consists of an inductance and capacity in parallel, in which a continuous high frequency oscillation, of very low amplitude, is maintained by some suitable device—generally a " valve "—explained in the next chapter.

For the present we will merely assume that this oscillation is set up, and its frequency is variable between very wide limits by adjustment of the condenser " C."

When there is no incoming signal, the frequency of the circuit LC alone is so high as to be inaudible, and no sound is heard in the telephones.

When a continuous wave strikes the aerial, two voltages will be acting on the detector: one at the frequency of the incoming wave, to which the aerial and secondary circuits are tuned, and one at the frequency of the heterodyne circuit, which is coupled to the detector circuit by the coil $L_2$.

Now, unless these two waves are of exactly the same frequency they will not rise and fall in time with one another, but will get into step and out of step alternately.

This action is illustrated in Fig. 231. Curve A shows the voltage due to the incoming wave at the frequency of the transmitting station which generated it.

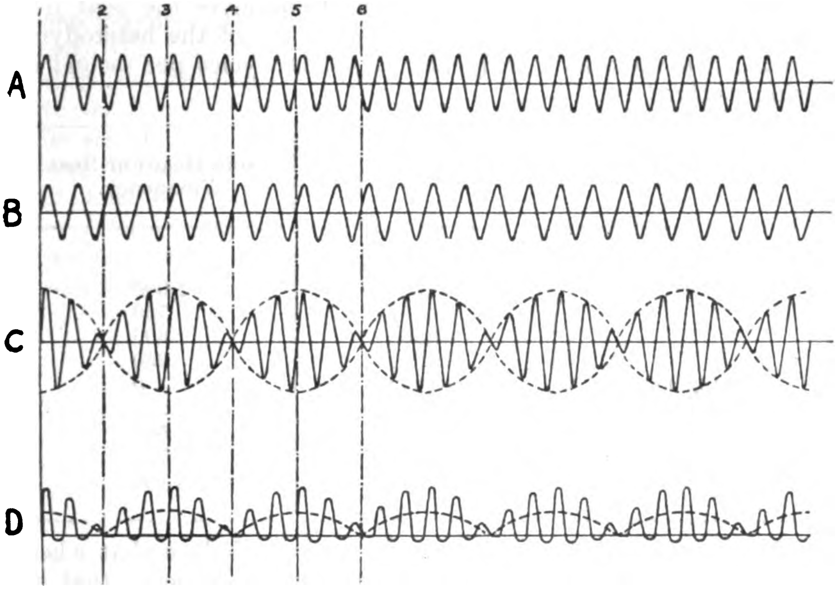


FIG. 231.

Curve B shows the voltage due to, and at the frequency of, the heterodyne circuit.

Curve C shows the combined effect of these two voltages as applied to the detector.

Curve D shows the rectified currents, and the mean telephone current variations, due to the rectification of the beat voltage.

At moments 1, 3, 5, &c., the two waves are in step; their combination gives a maximum of voltage acting on the detector, because the two voltages are acting in the same direction.

This, as can be seen from curve D, causes the rectified current, flowing into the telephone condenser, to rise to a maximum.

At moments 2, 4 and 6 the two waves are exactly opposite in phase; this means that the two voltages are trying to force current round the circuit in opposite directions. The combined effect is then at a minimum, and the telephone current, as shown in curve D, will fall to its lowest value.

Thus the interaction of the two waves gives rise to a "beat" voltage being applied to the crystal, rising to a maximum when the two waves are in step, and falling to a minimum when they are out of step.

Now, the frequency of these "beats" of voltage **is equal to the difference of the frequencies of the two component waves,** and the rectified current through the telephones will rise and fall at this "beat" frequency, giving a corresponding note.

**442.** To take figures, the following table gives the beat frequency corresponding to various adjustments of the heterodyne circuit, if a wave at a frequency of 48,000 cycles per second is being received :—

| Incoming Wave. | Heterodyne Circuit. | Note Heard or Beat Frequency. |
|---|---|---|
| Frequency in Cycles. | Frequency in Cycles. | |
| 48,000 | 49,000 | 1,000 |
| | 48,750 | 750 |
| | 48,500 | 500 |
| | 48,250 | 250 |
| | 48,000 | 0 |
| | 47,750 | 250 |
| | 47,500 | 500 |
| | 47,250 | 750 |
| | 47,000 | 1,000 |

From an inspection of this table we may deduce that when the frequency of the heterodyne circuit is the same as that of the incoming signal, no sound is heard in the telephones, because the two waves are completely in step. There will be a space on either side of this point where the beat note is so low as to be inaudible. This is called the "**Dead Space.**"

If the LC value of the heterodyne circuit is increased or decreased from this point a note is heard, which becomes higher the greater the difference of the two frequencies. Eventually it becomes so high as to be beyond the limit of audibility.

The same note can be obtained at two points, *i.e.*, points at equal differences of frequency above and below the dead space; *e.g.*, in the above example, a 500 cycle note is heard when the heterodyne circuit is set to 48·5 or 47·5 kilocycles.

The great advantage of the heterodyne system of reception can now be seen—that the note is absolutely under the control of the receiving operator. By a slight variation of the heterodyne condenser he can adjust the note in his telephone to any pitch that suits his hearing.

It is thus very easy to get over interference by over-reading.

For example, if an operator wishes to receive a signal of 10 kilocycles frequency, and interference is experienced at 9 kilocycles, he could either set his heterodyne to 10·7 kc. and read the signal as a 700 cycle note, while the interference would be heard at a 1,700 cycle note (which would be easy to over-read), or he could set his heterodyne to 9 kc., and read the signal at a 1,000 cycle note, while **the interference would be on his dead space,** and nothing would be heard of it.

It is important to note that when working with very high frequency signals (short wave-lengths), a very small alteration of the heterodyne circuit makes a very big alteration in note, and conversely, with long waves and low frequencies, the heterodyne circuit has to be thrown considerably out of tune with the incoming signal to produce a readable note. For example, to receive a signal from a transmitting station set to 30 LC at a 500 cycle note, the heterodyne circuit should be set to 29·96 or 30·03 LC, while for receiving a 10,000 LC wave at a 500 cycle note, the heterodyne circuit has to be set at 9,795 or 10,210 LC.

Hence great accuracy is required when working with short waves, and a small variation in the wave-length transmitted will cause a big variation in the note heard in the telephones.

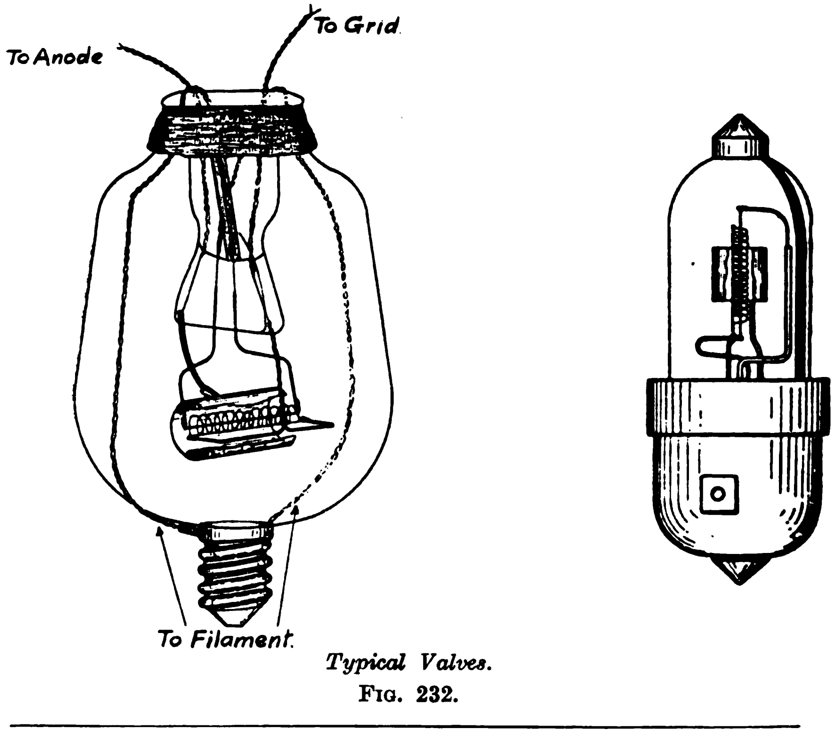
# CHAPTER XI.

## RECEIVING VALVES AND VALVE RECEIVING CIRCUITS.

**443. Thermionic Valves,*** sometimes known as "Thermionic Tubes," came into general use during the war. Their introduction has revolutionised the whole science of wireless telegraphy. They have replaced the crystal for detecting purposes. They are the most effective method of energising the heterodyne circuit, which is required for the reception of continuous waves. By their use in amplifier circuits, the use of "loop aerials," whether for ordinary or directional reception, has been made practicable.

As used in transmitting installations, they are rapidly replacing all other methods of energising an aerial, whether for telegraphic or telephonic purposes.

**444. Construction of Valves.**—Two characteristic types of receiving valve are illustrated in Fig. 232.



*Typical Valves.*

FIG. 232.

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* The terms "diode," "triode" are also used to indicate valves with two and three electrodes respectively.

Essentially, a valve consists of an exhausted glass bulb or "envelope," which contains the following three electrodes :—

(*a*) **The Filament.**—This consists of either a straight wire, or a loop, of tungsten, thoriated tungsten (*i.e.*, tungsten treated with a certain preparation to increase its emission), or platinum coated with lime. The two ends of the filament are brought to two suitable terminals outside the bulb.

(*b*) **The Grid.**—This consists either of a spiral coil of molybdenum wire, or a fine wire mesh cylinder, surrounding the filament. A single lead from the grid is brought to a terminal outside the bulb.

(*c*) **The Anode** (or Plate).—This consists of a nickel open-end cylinder placed outside and surrounding the grid. As in the case of the grid, a single lead is brought from the anode to the outside of the bulb.

Throughout this chapter a valve will be indicated diagrammatically as in Fig. 233.

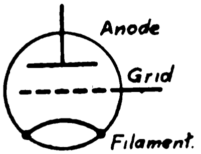


FIG. 233.

**445. Classification of Valves.**—Valves are classified according to two points in which their construction differs :—

(*a*) Their grid may be either a spiral of very few turns, when it is called an "Open Grid"; or it may be a spiral of a great many turns, or a close mesh of fine wire, in which case it is termed a "Close Grid."

(*b*) A valve may be exhausted so far as to be practically a perfect vacuum, in which case it is termed a "Hard Valve"; or it may have a small quantity of gas admitted into it after having been exhausted, in which case it is termed a "Soft Valve."

Hence valves may be spoken of as being—

| | |
|---|---|
| Hard Open Grid Valves. | Soft Open Grid Valves. |
| ,, Close ,, ,, | ,, Close ,, ,, |

**446. Design of Valves.**—The requirements involved in the design of receiving valves are as follows :—

Long life, durability and robustness.
Small filament current consumption.
Constancy.
Suitability for use on heterodyne circuits.
Effectiveness as detectors.
Silence for use in amplifiers.
Low capacity between electrodes.
Ease in manufacture.
Similarity of performance between all valves of the same type.

The reason for the various requirements will become evident after this chapter and the next have been read.

One valve seldom combines in itself all these properties at once, and valves are generally designed for one special purpose.

**447. The Filament.**—It was explained in Chapter II. that, in any conductor at ordinary temperature,

(*a*) the molecules are constantly on the move (para. **33**),

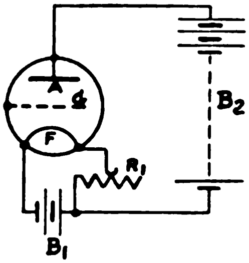
(*b*) this movement increases if the substance is warmed (para. **33**),

(*c*) at any moment there are always some electrons free from an atom, and darting from one atom to another (para. **37**).

It is found that, consequently on this molecular disturbance, if a substance is heated sufficiently some of the free electrons are continually being shot out of the metal. They will be attracted back again, because their absence leaves the metal positively charged.

Thus, any conductor, when heated above a certain temperature, is surrounded by a cloud or mist of electrons, which are continually being shot out and falling back into it again.

This property is utilised in the valve. The filament is heated up to a red or white heat by means of a low-voltage battery (as in Fig. 234), in series with which is joined an adjustable resistance $R_1$, to regulate the heating current flowing.



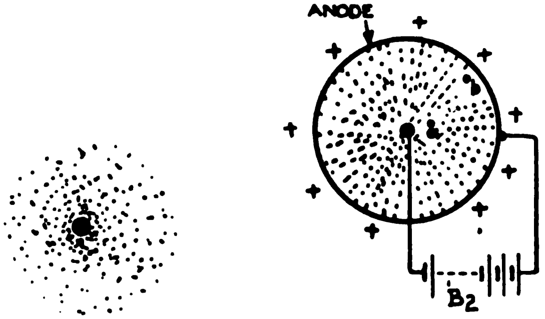
*Showing connections of Anode and Filament Batteries.*

FIG. 234.

Fig. 235 (*a*) shows a sectional end-on view of a filament. The grid, anode, and glass envelope are omitted for the moment. The filament is supposed to be heated by the battery $B_1$ shown in Fig. 234.

The dots in Fig. 235 (*a*) represent the electrons being shot off from the filament. They are densely crowded near the filament and sparsely scattered farther off.

**448. The Anode and Anode Current.**—Let us now join up the battery $B_2$ between filament and anode, as in Figs. 234 and 235 (*b*), so as to make the anode strongly positive with respect to the filament.



(*a*)
*Electron Distribution round Hot Filament.*

(*b*)
*Showing Electron Current between Filament and Anode.*

FIG. 235.

The negative electrons will now find themselves drawn across to the anode, instead of being allowed to fall back into the filament.

When they arrive at the anode they will pass along the conductor, through the battery, and back to the filament. Thus there is a definite current round the circuit comprising battery, valve and leads.

The current passing from filament to anode is a " convection " current (*see* para. **41**) consisting of electrons only, moving through a vacuum, while that flowing between the battery and the valve electrodes is the usual conduction current. In ordinary electrical parlance this current may be spoken of as flowing from the positive terminal of the battery, through the valve, and back to the negative terminal of the battery. In the case of receiving valves it is generally of the order of one or two milli-ampères at the most.

Both the batteries $B_1$ and $B_2$ are necessary; the former to liberate electrons from the filament, and the latter to drive the liberated electrons across to the anode.

**449. Limiting Conditions.**—As the anode voltage is steadily increased, the anode current steadily increases also, up to a point, where it meets with two limitations :—

(*a*) **Saturation Limit.**—A time comes when every electron that the filament emits is drawn across to the anode; then, however much the anode voltage is raised, the anode current cannot increase *unless* the filament heating current is also raised so as to liberate more electrons from the filament.

(*b*) **Space Charge Limit.**—Each electron that has left the filament is acted on by two forces :—

(i) the positive field of the anode (which attracts it),
(ii) the negative field of each of its brother electrons (which repels it).

Thus the electron marked *b* in Fig. 235 (*b*) will be

(i) strongly attracted by the anode,
(ii) strongly impelled onwards by the crowd of electrons behind,
(iii) weakly repelled by the few electrons in front;

and it will certainly reach the anode.

The electron marked *a*, on the other hand, will be strongly repelled by the crowd of electrons ahead of it, and may never feel the influence of the anode at all. It is found, therefore, that, even if the anode voltage and filament temperature are both raised, a limiting value of anode current is reached, due to the effect of this " space charge," as it is termed.

The effect of the space charge is overcome by the use of the grid as described in para. **452.**

**450. The Soft Valve.**—A " soft " valve is one which, after it has been pumped out (or " evacuated," as it is termed), has had a small quantity of gas—generally argon or helium—admitted into it.

The electrons do not now have an entirely unobstructed passage across to the anode. On the way many of them will strike atoms of the gas with enormous velocity. As a consequence of the collisions several more electrons will be shot out of each atom and will proceed on their way to the anode.*

An atom which has been struck, having lost electrons, becomes a " positive ion " (*see* para. **35**).

It will move off to the negative electrode (the filament), and on arriving there will push its way in among the cloud of electrons and will unite with a sufficient number of them to turn once more into a neutral molecule.

While so doing it enables more electrons to feel the influence of the anode by neutralising some of the " space charge " effect, and, as it were, " opening up the crowd " : consequently, more electrons are enabled to leave the filament. The result, then, of the **softening** of a valve is that the electron current is much denser than that in a similar hard valve for the same applied voltage.

The drawback is that the life of the filament is greatly shortened by the continuous impacts of the heavy positive ions, and therefore it burns out more quickly.

For this reason soft valves are never used in the Royal Navy and seldom in commercial practice.

The effect occurs to a small degree even in a hard valve, as no valve can be completely evacuated of all gas.

If a very excessive anode voltage is employed on the valve, the " ionisation by collision " becomes so vigorous as to produce a pale **blue glow** inside the valve. If the blue glow is allowed to persist for a few seconds the valve will be ruined.

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* This action will be familiar to anyone who has played " pyramids " or " snooker pool." When the cue ball strikes the pyramid at the opening shot, three or four balls shoot off from it on the other side.

**451. Dull Emitter Valves.**—As the name implies, dull emitter valves are those which will function at a low value of filament temperature and will therefore in general require smaller values of filament current than bright filament valves. The practical advantages of such valves are obvious and the use of dry cells for filament heating becomes possible.

The electronic emission of the filament depends upon its temperature and on the nature of the material of which it is made.

In order to increase the emission output at low temperature and consequently to reduce to a minimum the size of the filament batteries, filaments are made of "Thoriated Tungsten," which is a solution of thorium in tungsten. Thorium is a metal which has a very high specific value of thermionic emission (of the order of several thousand times that of tungsten at 1,700° C.). Although only a very small quantity of thorium is used (about 1 per cent.), if the filament is run for a while at a suitable temperature it presents a surface of pure thorium, owing to the diffusion of thorium to the surface from the interior of the filament with a corresponding increase of electron emission. The thorium surface, which is in the form of a very thin film, is very sensitive to the presence of traces of gas, and will be rapidly destroyed in a soft valve, or if the temperature of the filament is raised to a value at which thorium volatilises.

Valves of this nature have been made requiring only 1·8 volts and a filament current of 0·06 amps., but in this type the filament is very fragile owing to the extreme fineness of the wire used. Various other types are on the market all requiring values of filament voltage ranging between 1·8 and 3 volts, with a very small filament current up to about 0·25 amp. The most general type of low consumption dull emitter valve, as made by all the well known valve companies, takes 0·06 amp. at 3 volts.

Very satisfactory results are obtained with dull emitter valves as high frequency amplifiers, detectors and note magnifiers. The characteristics are very similar to those of bright filament valves, though in some cases a steeper slope is obtained owing to closer spacing of the electrodes.

Though practically immune from trouble from crackling, dull emitters almost invariably suffer from the defect of microphonic noises. At the low temperature at which they work, the filaments do not lose their elasticity and will be easily set in vibration.

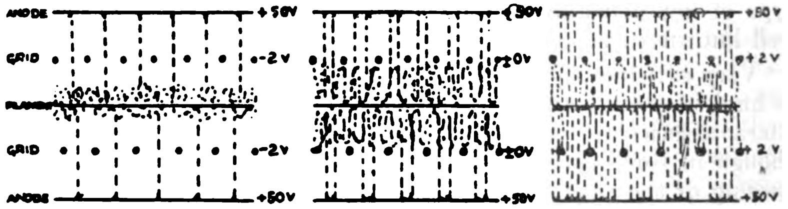
As regards the handling of dull emitters, it is found that if they are supplied with too high an anode potential their emission will fall off, owing to the destruction of the thorium film upon which their action depends, and to the traces of gas evolved from the cold electrodes, at a rate greater than the rate at which fresh thorium from the interior of the filament can diffuse to the surface. The emission will thus fall to the value corresponding to a pure tungsten surface. A filament damaged in this way may be restored to activity by burning it for a time without any potential on the anode. This will permit a new thorium film to be formed without the risk of damage from gas. The valve will then recover its normal emission.

There are types of dull emitters in which coated filaments are used consisting of platinum strip, coated with barium, strontium, and calcium, or other oxides, and others in which carbonised thoriated tungsten filaments are employed. For all types of dull emitter valves with thoriated tungsten filaments the very highest degree of vacuum is required. Valves in which coated platinum filaments are used are not quite so sensitive to the presence of traces of gas.

A method of preventing the contamination and destruction of the thorium film is to coat the internal surface of the bulb with magnesium. This is effected by welding a small fragment of magnesium to the anode and volatilising it when the anode is heated during the evacuation processes. Owing to its being more electro-positive than thorium any gases present combine with it rather than with the thorium. Bulbs treated in this manner have a silvery appearance and the filament can only be seen when incandescent.

**452.—The Grid.**—Let us now consider the effects of the grid. The grid forms an open screen between anode and filament. In practice its potential with respect to the filament is varied, with consequent alterations to the anode current.

Fig. 236 gives a section of the filament, grid and anode, and three conditions are illustrated, namely (*a*) when the grid is negative to the filament, (*b*) when grid and filament are at the same potential, and (*c*) when the grid is positive to the filament.



(*a*) *Grid Negative.* (*b*) *Grid Neutral.* (*c*) *Grid Positive.*

*Showing effect of different grid-filament potentials on the anode-filament current.*

Fig. 236.

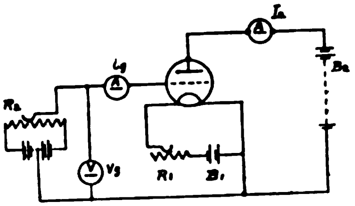
When the grid is negative to the filament (Fig. 236 (*a*) ) its field is acting in opposition to that of the anode, and tends to prevent electrons leaving the filament. As the grid is near the filament, a negative potential of two or three volts on it will be more effective in repelling electrons than the positive potential of (say) 50 volts on the anode will be in attracting them.

Thus, Fig. 236 (*a*) shows only a few electrons escaping through the grid to the anode.

When grid and filament are at the same potential (Fig. 236 (*b*)), the grid neither attracts nor repels electrons, and the only limitation on the anode current is the space charge effect.

When the grid is positive with respect to the filament (Fig. 236 (*c*)) its field will annul the effect of space charge due to the electrons beyond it on those just leaving the filament. Consequently, the anode current will be considerably greater than for condition (*b*).

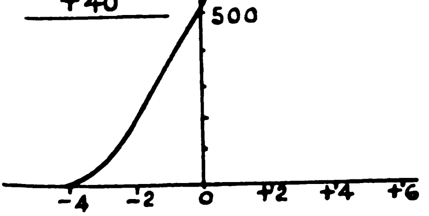
**453. The Grid Volts—Anode Current Characteristic.**—In order to examine more carefully the effect on the anode current (I*a*) of variations in grid potential (*Vg*), it will be convenient to arrange a circuit as in Fig. 237. Here we have the usual anode and filament batteries, and, in addition, a potentiometer for varying the grid-filament potential at will, together with suitable voltmeters and ammeters.



*Valve Testing Circuit.*

FIG. 237.

If a succession of simultaneous readings of grid voltage and anode current are taken, a curve of the type illustrated in Fig. 238 will be obtained.



*Anode Current—Grid Volts characteristic Curve.*

FIG. 238.

It will be seen that at – 4 grid volts the valve current is completely shut off.

Then, as the negative grid potential is decreased, the curve turns up sharply, showing that electrons are beginning to get across to the anode.

When grid and filament are at the same potential, the value of anode current is 500 micro-ampères.

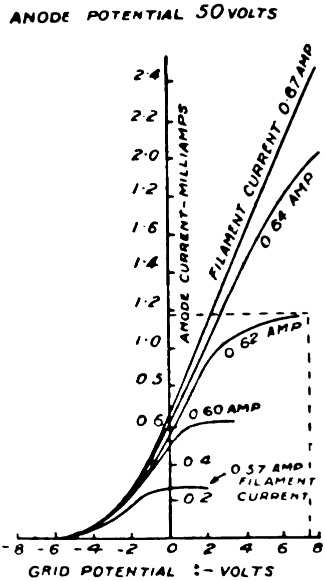
As the grid is made more positive, the anode current increases uniformly, until the value of 1,000 micro-ampères is reached.

After this point the curve becomes flat, showing that all the electrons which the filament can emit at its present temperature are reaching the anode.

The general shape of this characteristic curve depends on the construction of the valve: *i.e.*, on the distance between the electrodes, the spacing of the turns of the grid, &c.

**454. Effect of Filament Current Variation.**—If the voltage applied to the filament is varied by means of the rheostat $R_1$, the filament current will be varied with accompanying change of temperature. This will vary the possible electron emission from the filament, and consequently the moment at which saturation is reached.

For example, Fig. 239 indicates that, for a filament current of ·62 amperes, the saturation point on the anode current–grid volts curve is reached when the grid potential is + 7·5, the value of the saturation current being 1·18 milliampères; whereas when the filament current is reduced to 0·57 ampères, the saturation point is reached when the grid potential is zero, and the value of the saturation current is now only ·28 milli-ampères.

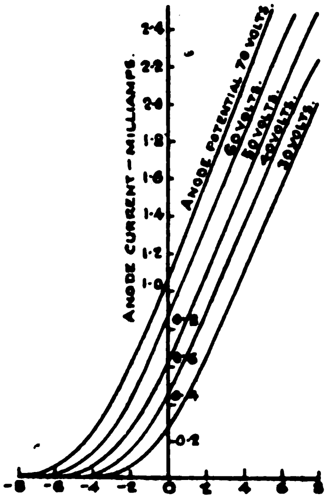


*Curves showing effect of Filament current variation.*

FIG. 239.

This result, of variations of the filament current causing the saturation point to be reached at different values of grid potential, is most important.

**455. Effect of Anode Voltage Variation.**—For any particular grid-filament potential, an increase of anode voltage results in an increase of current, subject to the limit of saturation. Plotting anode current-grid volt curves for different values of anode voltage, as in Fig. 240, we see that an increase of anode voltage results in the whole curve moving bodily to the left.



*Curves showing effect of Anode Voltage Variation.*
FIG. 240.

It will be noticed that an anode current of (say) 1 milliamp. can be obtained with 1·6 grid volts positive, and an anode voltage of 50, or with ·5 grid volts negative and an anode voltage of 70, thus showing what a big alteration in anode voltage is necessary to compensate for a small alteration in grid voltage.

**456.** We saw from para. **453** that a small change in grid potential produces a big change in anode current, and the valve as a whole is thus a delicate "Relay" for effecting a big change in a current for a small change in a voltage; so that a small change of current in a circuit joined between grid and filament may be made to effect a big change of current in another circuit joined between anode and filament; if this change of current is made to pass through an inductance, it will induce a big voltage across it.

It is for this reason that it is given the name of "Valve"—because it is like a valve in a steam engine, which effects a big change in the amount of steam passing through a pipe for a small movement of itself.

**457. Steady Potential of the Grid.**—In all the following diagrams the grid is shown connected to the positive end of the filament, as in Fig. 241 (*a*), because this is the usual arrangement in most circuits.

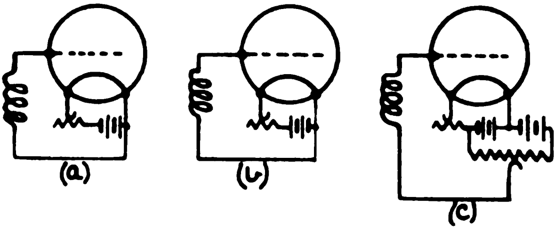


FIG. 241.

It is then at the same steady potential as the positive end of the filament.

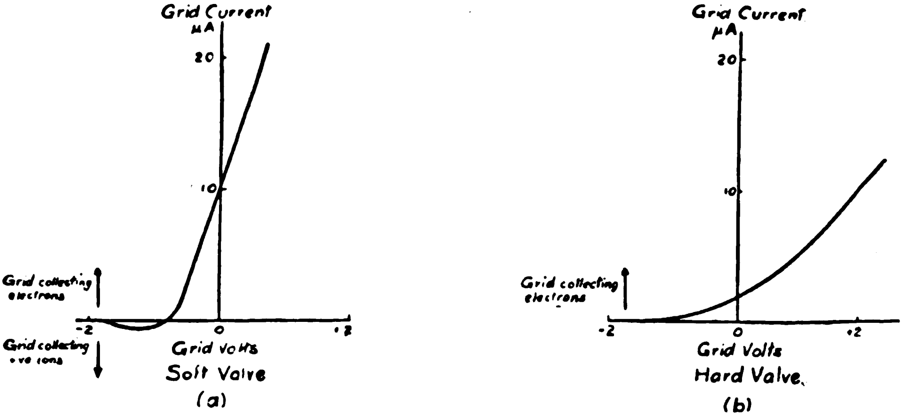
If it is desired to make it more negative, it may be joined up as in Fig. 241 (*b*), when it will be at the same potential as the negative end of the filament.

If it is desired to regulate its steady potential at will, it may be connected up to a potentiometer as in Fig. 241 (*c*). The effect of moving the potentiometer slider is equivalent to moving the origin line of the curve to the right or left.

The fall of potential along the filament must not be forgotten. For example, suppose that a 4-volt battery is joined across the filament, and that a 50-volt battery is joined between the anode and the negative end of the filament: then the P.D. between the anode and the positive end of the filament will only be 46 volts, and the electron emission from the filament will be heavier from its negative end.

**458. Grid Current–Grid Volts Curve.**—There is another property of the grid to consider, namely, its power of collecting electrons on itself from out of the stream passing through it.

Whenever the grid is positive to the filament, it will attract electrons to itself; the number so attracted will not be great, since the cross-sectional area of the grid itself is small compared to the spaces between its turns, and the majority of electrons are moving too fast through it to be deflected from their paths.



Soft Valve (a)

Hard Valve (b)

*Grid Current Curves.*

FIG. 242.

A curve to illustrate this point, and plotted with the help of the apparatus shown in Fig. 237, is given in Fig. 242 (*b*). We see that as the grid is made more and more positive, it collects an increasing number of electrons. Even when it is a little negative, it collects a few, as they are moving with such a high velocity that they are driven on to it in spite of its repelling effect.

Turning to Fig. 242 (*a*) we see that on the positive side its curve is much steeper than the hard valve curve (Fig. 242 (*b*) ); this is because the electron current is much denser, for the reason given in para. **451.**

On the negative side, the small dip of the curve below the line indicates that the grid picks up some of the positive ions that have been formed by collision.

This is termed the " backlash " current, or " reverse grid current."

The backlash current soon stops as the grid is made more negative, because such a large proportion of electrons are held back by the negative grid potential that very few positive ions are formed.

The reader should notice the difference in scale between Figs. 242 and 238. This shows that the grid current is very small compared with the anode current, but, nevertheless, this action must not be lost sight of, as considerable use is made of it for several purposes.

The similarity of the curve given in Fig. 242 (*a*) to the curve of the bornite-zincite couple, Chap. IX., Fig. 215, should also be noticed.

It must be remembered that the electrons picked up by the grid would otherwise have gone to the anode. A grid current is therefore a waste of energy, but nevertheless it has several useful applications.

**An increase of anode voltage** will increase the velocity of all electrons passing through the grid, and consequently will **decrease** the chances of the grid to attract them.

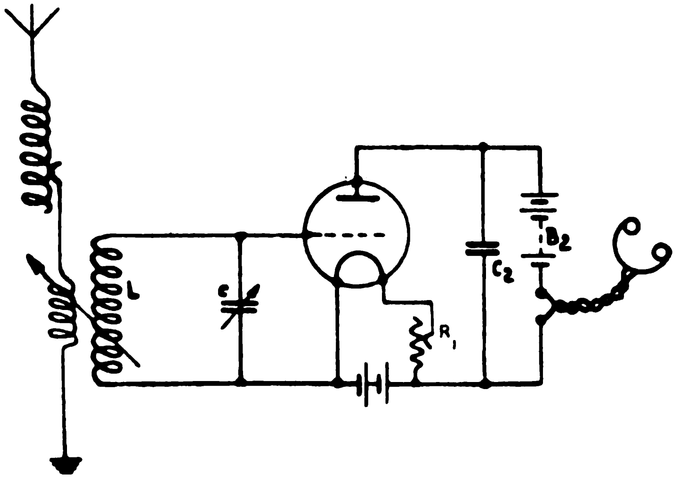
Therefore the grid current curve will move to the right if the anode voltage is raised—an effect opposite to that in the case of the anode current curve.

**An increase of filament current** increases the number of electrons emitted by the filament and in proximity to the grid : hence the grid current, or any particular grid potential, will increase if the filament current is increased.

Having covered this preliminary ground, we are now in a position to discuss how our first object, the use of a valve as a detector, may be attained.

**459. Valve used as a Detector.**—A valve may be used instead of a crystal for rectifying and thus detecting—*i.e.*, making audible, either the damped wave trains produced by a spark or

I.C.W. transmitter (*vide* Chapter XIII., para. 523) or the " beats " consequent on superimposing a heterodyne oscillation on a wave.



*Circuit for Anode or Grid Rectification.*

FIG. 243.

Fig. 243 shows a circuit which may be used as typical in describing the action of rectification.

The secondary circuit L C is joined directly between the grid and filament of a valve. Between the anode and filament of the valve are joined a battery ($B_2$) and a pair of telephones*, shunted by a condenser $C_2$. The valve filament is heated by current from the battery $B_1$, whose voltage is regulated by the resistance $R_1$. The steady potential of the grid will be the same as that of the negative end of the filament, since the two are joined together through the inductance L.

The anode is at a positive potential with respect to the filament, equal to that across the Battery $B_2$. We may therefore assume that the conditions illustrated in Fig. 238 and 242 (*b*) are prevailing. A steady current of 500 microampères is flowing through the valve, telephones and battery $B_2$, and a current of about 3 microampères is flowing round the grid circuit.

We now wish to show how rectification can occur in the above circuit.

It may occur due to one of three causes or a combination of two of them : (*a*) owing to the bend of the grid current curve; (*b*) owing to the upper bend of the anode current curve; (*c*) owing to the lower bend of the anode current curve.

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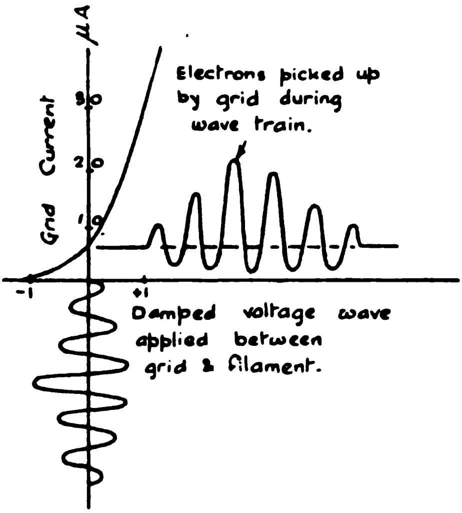
*NOTE.—In all cases where telephones are joined in series with a high tension battery, an unfair strain is thrown on their insulation, which is liable to suffer in consequence. It is better to use telephone transformers in combination with low resistance telephones. For the sake of clearness, however, the former arrangement has been adhered to in diagrams.

**460. Grid Rectification.**—Fig. 244 shows the grid current curve of Fig. 242 (*a*) on a slightly different scale.



*Illustrating Grid Rectification.*

FIG. 244.

If a damped oscillation is applied between grid and filament, whenever the grid is positive to the filament it will have a very strong tendency to collect electrons, whereas when it is negative to the filament this tendency will be small.

This effect is illustrated in the figure.

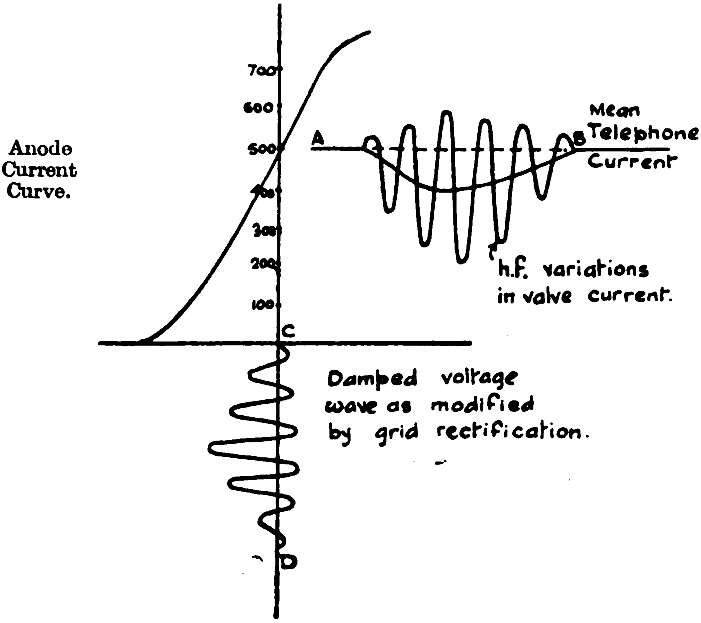
The curve below the horizontal line illustrates the positive and negative half cycles of voltage applied to the grid, and the curve on the right shows the electrons which are picked up by the grid in consequence.

Positive half cycles tend to give the grid a positive charge, which attracts negative electrons; **these electrons partially neutralise the positive charge** which the half cycle is trying to build up on the grid. On the other hand, the negative half cycles produce their full effect, which, in fact, may be slightly augmented by a few electrons picked up (*vide* Fig. 244).

When the grid becomes negative, the resistance of the space between grid and filament is infinite; but when the grid becomes positive, a grid current is established which lessens the resistance of the valve and tends to damp out the positive half oscillation.

Thus each positive half cycle on the grid is diminished in amplitude, and the curve of oscillatory voltage shown in Fig. 244 is altered to that shown below, about the vertical line C D, Fig. 245, becoming asymmetrical.

Let us now consider the effect of all this on the anode current. We start with $500\mu$ A flowing through the valve and telephones (as in Fig. 245).


Anode Current Curve.
700
600
500
400
300
200
100
A
B
C
D
Mean Telephone Current
h.f. variations in valve current.
Damped voltage wave as modified by grid rectification.

*Illustrating Grid Rectification.*

FIG. 245.

Tracing out in Fig. 245 the alterations in anode current (on the right) consequent on the alterations in grid voltage (shown below), we see that in the middle cycle the current through the valve only rises to $600\mu A$ and falls to $200\mu A$.: that is to say, the decrease during the negative half cycle ($-\ 300\mu A$) is very much greater than the increase during the positive half cycle ($+\ 100\mu A$). We may regard the high frequency asymmetrical changes of anode current as being made up of two components :—

(*a*) high frequency symmetrical changes about the line AB, and

(*b*) a low frequency fall and rise of anode current,

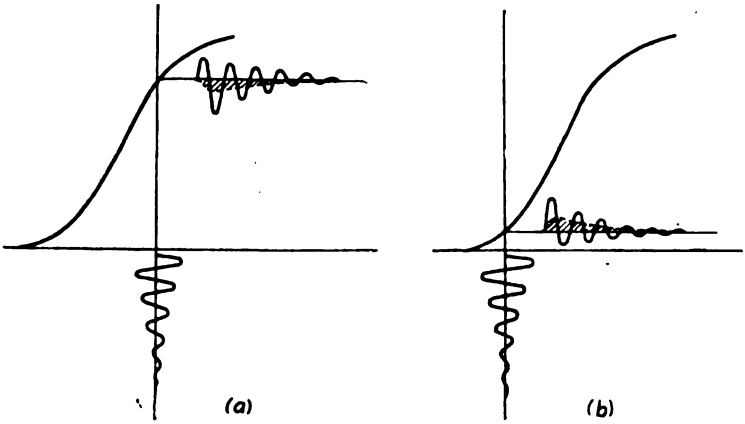
the asymmetrical oscillation being the **resultant** of these two.

The telephones, on account of their large inductance, will not pass the high frequency symmetrical changes, which find an easy path through the condenser $C_2$, whereas the condenser cannot pass the low frequency fall and rise, which finds an easy path through the telephones.

NOTE.—A similar action occurs, though not so effectively, if we omit the condenser, $C_2$; in this case the high frequency changes are passed through the natural capacity of the windings of the telephone itself.

**461. Anode Rectification.**—It has already been explained that the characteristic curves of the valve can be altered by altering (*a*) the filament temperature, (*b*) the grid potential,

(c) the anode potential. Let us dull down our filament till we get the curve shown in Fig. 239 as corresponding to a filament current of 0·6 amp.



*Illustrating Anode Rectification.*

FIG. 246.

We are now working on the upper corner of the anode current curve, as illustrated in Fig. 246 (*a*). Hence we have a perfectly symmetrical variation in grid voltage (for we are neglecting the grid rectification effect previously explained), but the resulting variations in anode current are not symmetrical. Owing to the bend in the anode current curve, the increases of current when the grid is made positive are less than the decreases of current when the grid is made negative. One can again resolve this asymmetrical oscillation into two components—one at high frequency, which will be passed by the condenser, and one at low frequency, which will pass through the telephones. Thus the mean valve current is decreased, and the result of the whole wave train will be that the unidirectional current through the telephones will **fall**, as indicated by the dotted line in Fig. 246 (*a*).

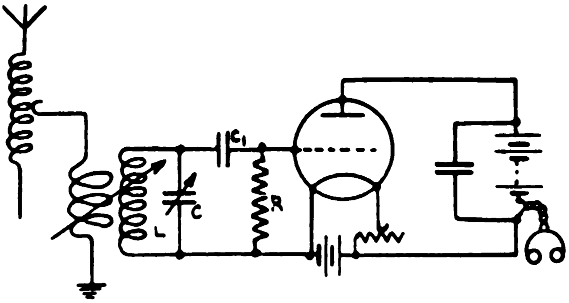
**462.** Again, let us move the anode characteristic curve to the right, either by decreasing the anode voltage (para. **453**) or by inserting a grid potentiometer and applying negative grid potential (para. **398**), until the zero line cuts the curve at its lower bend, as in Fig. 246 (*b*).

Rectification will again occur, but in the opposite sense. Positive grid voltages will cause a large increase of anode current, and negative grid voltages a small decrease.

Thus a wave train will give rise to an increase in the mean battery and telephone current, and a corresponding movement of the telephone diaphragm.

**463.** It can easily be imagined that suitable adjustments of filament current, anode voltage and grid potential will enable us to make use of both anode and grid rectification, and in practice many combinations of adjustment can be found which give equally good results. From the foregoing explanations of grid and anode detecting it should be clear that when using the anode detecting method, a grid detecting action must also take place unless the grid is given a negative bias by a potentiometer. This action will assist the anode detecting action when working on the upper bend of the anode current curve, and oppose it when working on the lower bend.

### 464. Cumulative Grid Rectification



*Circuit for cumulative Grid Rectification.*

FIG. 247.

Fig. 247 illustrates the secondary of a receiving circuit (L C) for damped waves joined between grid and filament of a valve, the grid being insulated by a condenser, $C_1$. Between grid and filament is joined a resistance R of some value between one and two megohms. It is termed a " Grid Leak."

Between anode and filament are joined the high potential battery, a pair of telephones, and a condenser in parallel.

**Action.**—Before any wave strikes the aerial, the grid potential will be the same as that of the filament, and a steady current will be flowing from the battery, through the valve and telephones, corresponding to this potential.

When a damped wave-train strikes the aerial, the grid-filament potential will be varied as shown in Fig. 248 (*a*) (i).

The variation of grid current, under the influence of the oscillatory voltage, is similar to that described in para. 460 above.

**Since, however, the grid is insulated,** except for the grid leak R, these charges cannot escape nearly as fast as they collect (as they did before).

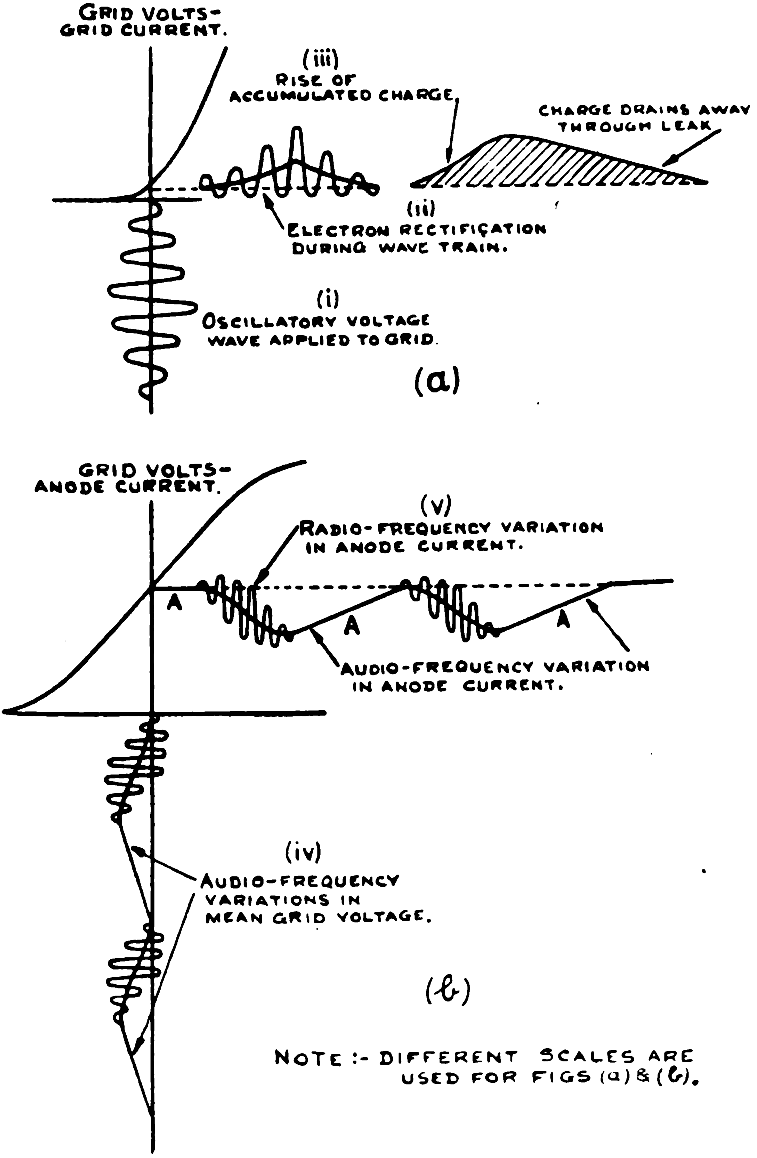
The result of the wave train will therefore be that the grid will accumulate, or " rectify " a negative charge on itself, as indicated by the shaded area at (iii).

When the wave train is over, this charge will leak away to the filament as also indicated at (iii).

A succession of wave trains will therefore result in a **rise and fall of negative grid potential** at audible frequency.

Turning to Fig. 248 (*b*), which indicates how changes in grid potential affect the main anode current, we see that we have two changes in the grid potential (iv) occurring simultaneously :—

(*a*) The low frequency change, due to the grid rectification, which affects the steady current flowing from the high potential battery and through the telephones (v), as indicated by the line AA.



*Illustrating cumulative Grid Rectification.*

FIG. 248.

These low frequency changes **will result in movements of the telephone diaphragm,** once for each incoming wave train.

(*b*) The high frequency change, due to the incoming wave, which is superimposed on the low frequency change, and produces an oscillatory change in the anode current, at the frequency of the aerial circuit of the transmitting station.

The inductance of the telephones is too great to allow the current through them to change at high frequency, and the high frequency change will therefore be "passed" by the condenser $C_2$.

To sum up: any oscillation of varying amplitude applied between grid and filament will result in the collection or rectification at the grid of a negative charge of varying amplitude. This charge will effect a fall in the mean valve and telephone current—and therefore a movement of the telephone diaphragm—once for each accumulation of negative charge on the grid.

Thus the note heard in the telephones will depend on the spark train frequency of the transmitting circuit.

The above process is known as "cumulative grid rectification," and is rather more effective than when the grid condenser is omitted, as in para. **460.**

**465. The Grid Leak.**—The value of the grid leak resistance is an important consideration.

If it is too low a resistance, the rectified charge will drain away practically as fast as it collects, with the result that the main telephone current will not be altered much, and signals will not be as strong as they might be.

If it is too high a resistance, an atmospheric striking the aerial will induce a big negative charge on the grid which will take a very long time to drain away through this high resistance, and the valve will be "thrown off," or rendered unable to rectify at all for several seconds, during which time part of a signal may be missed. If it is not there at all, the only escape for the charge is through the valve itself, thus giving a much worse "wiping out" effect.

It should be of such a value that the rectified charge has just drained away before the next wave train starts.

Sometimes a very large inductance, of the order of henries, is used instead of a resistance. Its effect is the same—of preventing a grid charge draining away as fast as it collects.

**466. Comparison of Valve and Crystal Detecting.**—When a crystal detector is used, the rectified charge is stored in the telephone condenser and passed straight through the telephones.

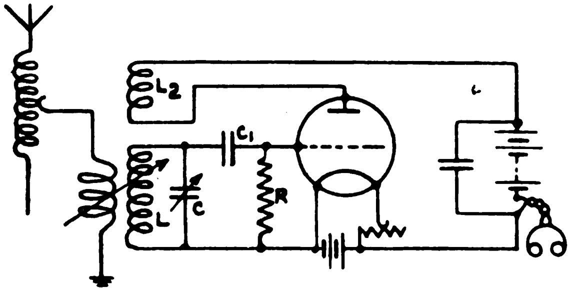
When a valve is used as a detector, the small rectified charge on the grid is used to make a big change in the mean anode and telephone current.

There is thus a "Relay" action, which is a much more effective way of using the rectified charge.

On the other hand, the grid current curve of a valve is not as steep as the characteristic curve of a good crystal.

**467. Regenerative Amplification.**—It was mentioned above that the valve current has not only the low frequency variation which operates the telephones, but also a high frequency variation which passes through the condenser $C_2$. This high frequency variation has the same frequency as that of the incoming wave.

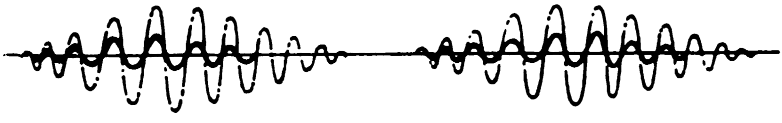
So far we have not made any use of it. Let us now join in the "**reaction coil**" $L_2$ between the anode and the high tension battery as in Fig. 249.



*Circuit for regenerative amplification and detecting, or autodyne reception.*

Fig. 249.

If this coil $L_2$ is brought near the secondary inductance L, the high frequency changes of current in it will induce high frequency changes in voltage in the circuit LC. Now these induced E.M.F.s are exactly in phase with the oscillation induced by the incoming wave in the circuit LC, since this is the very cause of their existence; they will therefore tend to build up and maintain the secondary oscillation, provided that the coil $L_2$ is joined up in the right direction; if not, they will merely oppose it, and damp it out.



*Effect of regenerative amplification in increasing persistency.*

Fig. 250.

This effect is known as "Regenerative Amplification." The incoming wave ordinarily suffers a damping effect due to the various resistance losses of the receiving circuit. If, however, the coupling of coil $L_2$ to L is carefully adjusted, the signal will be found to be considerably increased in strength, **because** the energy derived from the valve circuit is used to **neutralise the damping of the receiving circuit.** For example, the signal might have been damped out as shown by the full line curves in Fig. 250 : owing to the assistance thus given it, it is prolonged as indicated by the dotted line curves. The whole receiving circuit is brought to a condition when it is set in oscillation with the greatest ease by any applied impulse of the correct frequency.

(It should be remembered that in the reception of damped waves as above, all circuits must be tuned to the incoming signal frequency, whereas in the reception of C.W. the circuit in which the heterodyne oscillation is generated must be mistuned so as to give the desired beat note.)

This method of amplification is most valuable, provided that it is readily controllable, and it has numerous applications in the reception of damped wave trains, whether spark, I.C.W. or R/T. The coupling of $L_2$ to L can be increased up to the point when each wave train dies away just before the next starts. If the process is continued too far a continuous oscillation will be set up, quite irrespective of the incoming wave, and the spark note in W/T, and the speech in R/T, will be spoilt.

**468. Use of a Valve for Heterodyne Purposes.**—We will now describe how the above circuit may be used to heterodyne a continuous wave.

To commence with, assume that no signal is affecting the aerial.

Let the reaction coil $L_2$ (Fig. 249) be placed considerably closer to L than was required for regenerative amplification.

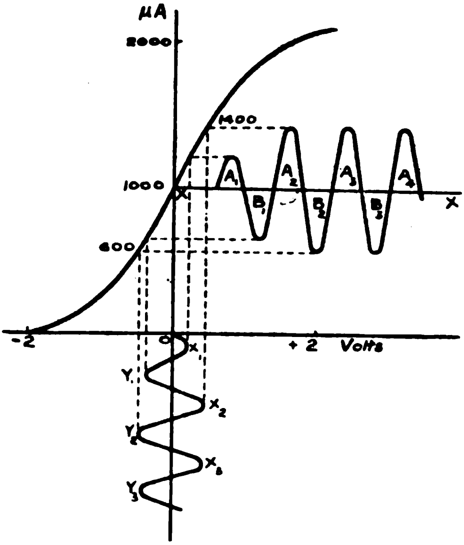
As soon as the filament current is switched on, and the high potential applied to the anode, a current corresponding to zero grid potential (indicated by the line OX, Fig. 251) will flow through the valve from the high potential battery, passing on its way through the inductance $L_2$.

Now the circuit LC is just as ready to start oscillating as is the balance wheel of a watch, when the watch is wound up and given a slight shake.

Consequently, the mere fact of switching on the filament and anode batteries will make the circuit LC give a slight oscillation at its own natural frequency.

This oscillation will induce an oscillatory E.M.F. across the condenser C, and consequently the polarity of the grid will be altered, being first made positive and then negative, as indicated by the half-cycles of voltage $X_1$ and $Y_1$ shown in Fig. 251.

As can be seen from the curve, these alterations in grid potential cause an alteration in the valve current, first increasing



*Illustrating growth of self-oscillation.*
FIG. 251.

it and then decreasing it, as shown by the half-cycles of current $A_1$ and $B_1$.

These alterations in current in the circuit LC passing through the inductance $L_2$ will induce E.M.F.'s in the circuit LC which will tend to maintain and increase the initial oscillation.

As the oscillations in the circuit LC build up they increase the oscillating voltage applied to the grid, and consequently effect a greater and greater change in the anode current.

The amplitude of the self-oscillation rapidly builds up to a steady value depending on the one hand on the damping losses in the circuit LC, *i.e.*, on the actual amount of power which has to be drawn from the valve, and on the other hand on the tightness of coupling between L and $L_2$, the steepness of the anode current curve, the value of the filament current and anode voltage, and on other such factors which determine in greater or less measure the power which the valve can actually supply.

It will be clear that it is the attainment of a balance between the amount of power required by the circuit and that which the valve can actually supply which determines the final value of the oscillating current.

It should be noticed that the oscillating current rises and falls an equal amount on either side of the straight line XX, because the anode current curve is straight for the range over which we are working.

During the positive half-cycles the current increases to 1,400 microampères, and during the negative half-cycles it falls to 600 microampères.

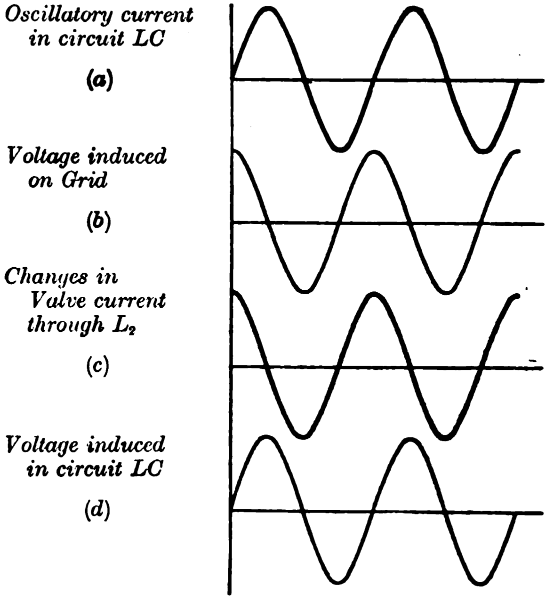

Oscillatory current in circuit LC
(a)
Voltage induced on Grid
(b)
Changes in Valve current through $L_2$
(c)
Voltage induced in circuit LC
(d)

FIG. 252.

It can therefore be said that the high potential battery supplies a steady current equal to the mean of these two —1,000 microampères—while the oscillatory current of ± 400 microampères flows through the condenser $C_2$.

**469.** The fact that the E.M.F. induced in the circuit LC which arises from the changes of anode current will assist the original oscillation can be seen in the following way :—

The induced E.M.F. in LC (Fig. 252 (*b*)) will be 90° out of phase with the oscillatory current in LC (Fig. 252 (*a*)).

The rise and fall of anode current (Fig. 252 (*c*)) follows the rise and fall of grid potential.

The induced E.M.F. in LC (Fig. 252 (*d*)) due to the changes in anode current will be 90° out of phase with the changes in the anode current, and therefore in phase with the original oscillation; they thus assist to maintain it, if the reactance coil $L_2$ is joined up the right way round.

Of course, if the coil $L_2$ is joined up in the reverse direction, the E.M.F. induced across LC will tend to stop the oscillation instead of maintaining it, which is not what we want in this case.

We have now seen how a valve may be used for setting up a uniform high frequency oscillation in a circuit.

**470. Auto-heterodyne Circuit.**—The circuit shown in Fig. 249 may be used conveniently both to heterodyne an incoming continuous wave, and also to rectify the resultant " beats " due to the interaction between the incoming wave and the heterodyne oscillation.

Assume firstly that the circuit LC is oscillating steadily, as described above.

Assume also that the circuit LC is mistuned to the aerial circuit, being tuned to a frequency $f'$ which is slightly different to that of the incoming wave (of frequency $f$).

The action is as follows :—

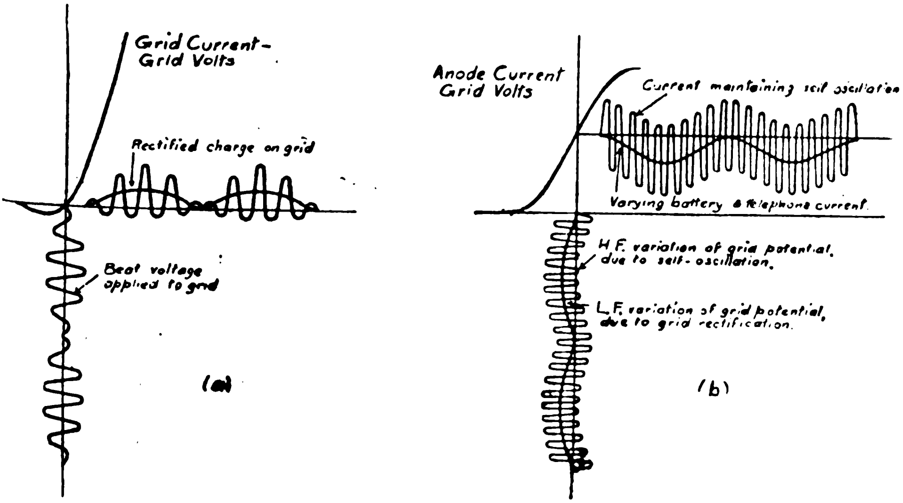
While the circuit is oscillating (as explained in para. **468**) the grid will be steadily rectifying a certain charge on itself, which charge will be steadily draining away through the grid leak.

As soon as an incoming continuous wave strikes the aerial, it will set the aerial circuit (which is tuned to it) in oscillation, and will also set up an oscillation in the circuit LC, which is slightly mistuned to it.

There will thus be two high frequency oscillations applied between grid and filament, one at the frequency $f$ of the incoming wave and one at the frequency $f'$ of the circuit.

These two voltages being superimposed will combine to produce a " beat " rise and fall of voltage at a frequency equal to the difference in frequencies of the incoming wave and the heterodyne circuit.

This will result in a rise and fall of negative grid potential, as illustrated in Fig. 253 (*a*) and (*b*).


Grid Current-
Grid Volts
Rectified charge on grid
Beat voltage applied to grid
(a)
Anode Current
Grid Volts
Current maintaining self oscillation
Varying battery & telephone current.
H.F. variation of grid potential, due to self-oscillation.
L.F. variation of grid potential, due to grid rectification.
(b)

*Illustrating autodyne reception.*

FIG. 253.

This, again, will result in a low frequency rise and fall of the mean anode, battery and telephone current, at audio-frequency, as illustrated by the thick line, Fig. 253 (*b*).

In Fig. 253 (*b*) is also shown the high frequency change in grid-filament voltage, due to the self-oscillation of the circuit LC, which will lead to the high frequency changes in anode current (as shown by the thin line) which maintain the self-oscillation.

(It must not be forgotten, however, that there are two high-frequency currents flowing in the circuit LC, the self-oscillation current and the current due to the incoming wave, which, added together, give a "beat" current. For the sake of clearness, the current due to the incoming wave has been omitted.)

The heterodyning and detecting actions are thus occurring simultaneously in the same circuit.

**The best condition** for combined heterodyning and detecting is when the self-oscillation is not unduly strong compared with the incoming signal, and this condition can be obtained by reducing the anode voltage, reaction, or filament current, until the changes in anode current are only just sufficient to maintain the self-oscillation.

**471. Use of Heterodyne and Auto-heterodyne Circuits.**—The operation of detecting may be combined with that of heterodyning in one circuit as just described. Such a circuit is known as an "Auto-heterodyne."

Alternatively, a separate circuit may be used for generating the heterodyne oscillation, which is then transferred through a coupling coil to the detector circuit. The detector may be a crystal or a valve, as most convenient.

The auto-heterodyne arrangement is simple and easy to handle. It has, however, two disadvantages :—

> (*a*) In order to obtain the heterodyne "beat," the circuit must be thrown out of tune with the incoming wave, which is consequently weakened. This loss is particularly serious in the case of long waves, and for the reception of these it is generally best to use a separate heterodyne.
>
> (*b*) It is difficult to prevent the heterodyne wave from being radiated by the aerial : interference is consequently caused to other receiving sets working on the same wave.

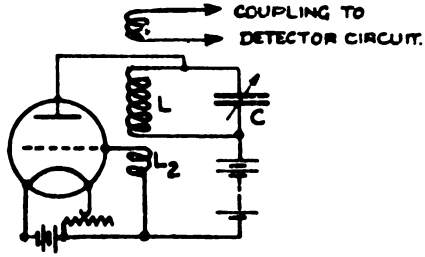
Both these difficulties may be avoided by the use of a separate heterodyne circuit.

On the other hand, a separate heterodyne means another valve in use, another circuit to adjust, and more space occupied.

Any of the circuits shown below may be used, either as auto-heterodynes, or as separate heterodyne circuits. In the first case the coupling coil is joined directly in series with the aerial circuit, and in the second case in series with the detector circuit.

The actual value of the inductance used in the coupling coil will depend upon the method in which the circuit is employed.

**472.** A very simple and effective form of heterodyne circuit is shown in Fig. 254.



*Simple heterodyne circuit.*

Fig. 254.

Here the oscillatory circuit is joined in the anode lead, while the reaction coil is joined to the grid.

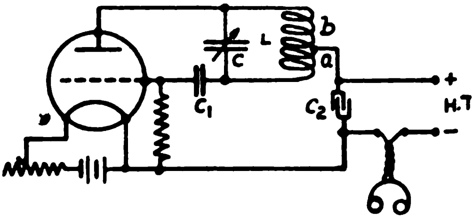
The action is similar to that described above in para. **468.** Any small oscillation starting up in the circuit LC will induce an oscillatory E.M.F. on the grid.

The varying E.M.F. on the grid will cause variations in the anode current which, passing through the circuit LC, will build up and maintain the initial oscillation. Two requirements must be fulfilled :—

(*a*) The coil $L_2$ must be so joined up that the variations in valve current induce E.M.F.s in the oscillatory circuit which assist, and do not oppose, the initial oscillation.

(*b*) The energy supplied by the valve must be sufficient to make good the damping losses of the circuit.

**473. Direct Coupled Circuit.**—Another form of auto-heterodyne circuit is shown in Fig. 255.



*Direct coupled auto-heterodyne circuit.*

Fig. 255.

In this case the grid is coupled directly, instead of inductively, to the oscillatory circuit.

The circuit from grid to filament runs from the grid, through the condenser $C_1$, through the portion " a " of the main inductance L, through the condenser $C_2$, to the filament.

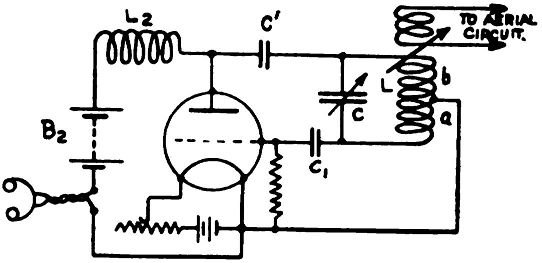
(*a*) **Heterodyning Action.**—When the high tension and filament batteries are switched on, the rise of current through the inductance L will induce a voltage across the inductance "a," which in turn will be applied between grid and filament.

This change in grid filament voltage will effect a change in the anode current passing through the portion "b" of the inductance L, and will therefore induce a voltage across it which will start an oscillation in the circuit LC.

This oscillation will build up to a value depending on the power output from the valve and the losses in the circuit LC.

(*b*) **Detecting Action.**—When the amplitude of the oscillatory voltage applied between grid and filament is varying at audio-frequency, either on account of an incoming damped wave train, or on account of the interaction of an incoming continuous wave with the self-oscillation referred to above, then the rectified charge of the grid will rise and fall at audio-frequency; this low frequency variation in grid potential will lead to a similar variation in the anode and battery current, which, passing through the telephones, will give a corresponding note.

**474.** Another variation met with is the method in which the high tension voltage is applied, as shown in Fig. 256.



*Parallel Feed Circuit.*

Fig. 256.

Here the valve and oscillatory circuit are in parallel—whereas in Fig. 255 they are in series—and the high tension voltage is applied through a choking coil $L_2$.

The condenser C′ is merely an insulating condenser preventing a short-circuit of the high tension supply through the inductance L.

(*a*) **Heterodyning Action.**—The explanation of the heterodyning action is different from any given previously, and is as follows :—

The mean steady current flowing from the battery $B_2$ through the valve will be that corresponding to zero grid potential—let us say 1,000 microampères.

This current will be kept constant by the inductance $L_2$, which will prevent any **high frequency** changes in it.

Now any oscillation starting up in the circuit LC will vary the grid-filament potential, and will consequently vary the current the valve will pass.

Let us suppose that when the grid is made negative it will only allow a current of 700 microampères to pass through the valve.

Since the inductance $L_2$ keeps the current of 1,000 microampères flowing, a current equal to the difference between these two—*i.e.*, $1{,}000 - 700 = 300$ microampères—will be deflected into the condenser C′, charging it up.

Let us again suppose that when the grid is positive the resistance of the valve falls so much that it will allow a current of 1,300 microampères to pass.

Then the charge just stored in the condenser C′ will cause a current of 300 microampères to flow back, so that the valve current will be $1{,}000 + 300 = 1{,}300$ microampères.

This flow of current into and out of the condenser C′ will be timed by the frequency of oscillation of the circuit LC, and will cause a similar current to flow into and out of the other side of the condenser and through the portion "b" of the inductance L, thus maintaining the high frequency oscillation of the circuit LC.

The valve current can thus be looked upon as made up of two components :—

(1) A steady component of 1,000 microampères from positive to negative of the high tension battery through the valve and telephones.

(2) An oscillatory component of 300 microampères through the condenser C′, the portion "b" of the inductance L, and the valve.

(*b*) **Detecting Action.**—As before, when the amplitude of the oscillatory voltage applied between grid and filament is varied at audible frequency by an incoming signal, there will be an audio-frequency variation in the mean grid potential, and in consequence an audio-frequency variation in the current flowing from the high tension battery through $L_2$, the valve, and the telephones, which will give rise to an audible sound.

It will be noted that the value of the inductance $L_2$ should be such as to impede a radio-frequency variation, but permit a audio-frequency variation, of the current passing through it.

**475.** The whole problem of reception is so bound up with the problem of amplification that any further consideration of valve receiving circuits must be deferred to the next chapter.

## CHAPTER XII.

### AMPLIFIERS.

**476**. An Amplifier is a combination of valves and suitable circuits for increasing the strength of signals.

With all forms of relay embodying actual moving masses, as in a " Brown's " relay, difficulties are experienced owing to the inertia of the moving parts, which cannot be made small enough to enable them to move at the high frequencies used in oscillatory circuits for wireless work.

In a **valve** the only moving parts are electrons and ions, and these are so light that under the electric fields commonly employed there does not appear to be any appreciable time lag up to 50 million cycles per second.

**477.** It will have become apparent from the last chapter that if any small variation of voltage is applied between grid and filament of a valve, a considerable variation in the anode current will take place.

If this variation in current is applied to a resistance, inductance or condenser joined in the anode circuit, a variation in voltage will occur which may be greater than that originally applied between grid and filament.

This is the fundamental principle of valve amplification.

**478.—Amplification.**—A simple form of valve amplifier is that shown in Fig. 257.

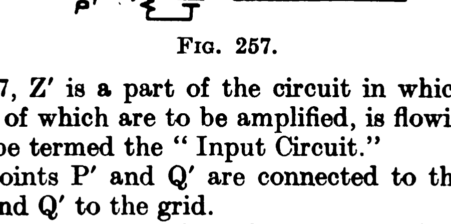


FIG. 257.

In Fig. 257, Z′ is a part of the circuit in which the current, the variations of which are to be amplified, is flowing.

This may be termed the " Input Circuit."

The two points P′ and Q′ are connected to the valve, P′ to the filament and Q′ to the grid.

The battery $B_1$ provides the current for heating the filament.

This current is controlled by the rheostat $R_1$.

A battery $B_3$ and potentiometer $R_3$ are connected between the grid and filament for adjusting the mean grid voltage to the most sensitive point on the characteristic curves.

The positive voltage of the anode is provided by the battery $B_2$.

The circuit Z, in which the amplified current variations are to be produced, is in series between this battery and the anode.

This may be termed the " Output Circuit."

**479. Action.** Any small changes in current in the input circuit Z′ lead to small changes in the voltage of Q′ with respect to P′, and consequently to small changes superposed on the voltage maintained between the grid and filament by the battery $B_3$ and the potentiometer $R_3$.

These changes between the grid and filament in turn lead to changes in the anode current passing through the output circuit Z. With suitable circuits and adjustments, the changes of P.D. across the circuit Z can be made to be much greater than the changes of P.D. across the input circuit Z′.

Considering for the moment only the Anode Current-Grid Voltage characteristic, of which Fig. 258 is an example, it is clear that the steady voltage maintained between the grid and filament should correspond to the point K on the curve, because a given change of grid voltage then causes the largest change of anode current.

If the grid potential is varied between zero and — 1 volt, the change of anode current is from 1·4 to ·4 milliampères, *i.e.*, a change of 1 milliampère per volt. (The changes usually obtained in practice are about 1/5th of this, but the round number is taken for purposes of illustration.)

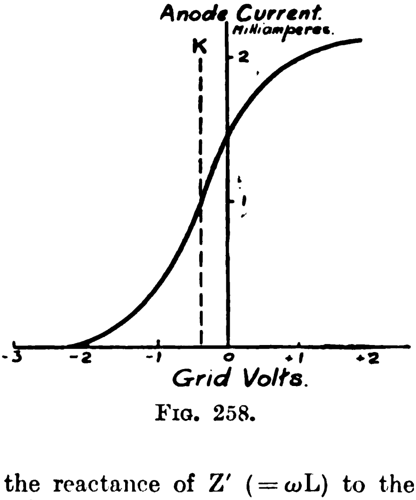


FIG. 258.

**Example 56.**

Assume that the reactance of Z′ ($=\omega L$) to the current passing through it is equivalent to 100,000 ($10^5$) ohms, and that the increase of current to be amplified is one-tenth of a microampère $\left(\frac{1}{10}\mu A\right)$.

Increase of current to be amplified $= \frac{1}{10}\mu A$.

Increase of P.D. across $Z'$ and between grid and filament $= \omega LI = 10^5 \times \frac{1}{10} = 10^4$ microvolts $= \frac{1}{100}$ volt.

With an anode current — grid volts' slope of 1 milliamp. per volt, the increase in anode current would be :—

$$\frac{1}{100} \times 1000 = 10 \text{ microamps.},$$

giving a ratio of output current change: input current change $: : 10 : \frac{1}{10}$, or $100 : 1$.

Now this increase of current of 10 microamps. passes through the output circuit of reactance Z ohms, and will induce a voltage across it of $10 \times Z$ microvolts.

From the ordinary laws of induction, this induced voltage will act against the applied voltage—*i.e.*, away from the anode—and will consequently **decrease** the anode voltage.

The decrease in anode voltage will lessen the increase in anode current (*see* Fig. 240, Ch. XI). Hence the voltage induced across Z will not be as great as it would have been had the anode voltage remained steady.

Similarly, a decrease in anode current will result in an induced voltage across Z which will raise the anode voltage, and tend to lessen the decrease in anode current.

If, therefore, the impedance of the output circuit is made too great, the variations in voltage across it may be less than those across the input circuit.

There will clearly be a best value for the impedance of the output circuit which will give the greatest power amplification for any voltage variation between grid and filament.

The expression $\frac{dV_a}{dI'_a}$—*i.e.*, the ratio of anode voltage change to anode current change—is sometimes termed the "**effective resistance**" of the valve.

It can be shown mathematically that the valve gives the greatest power amplification when the impedance of the output circuit $Z = \frac{dV}{dI'_a}$, just as in the case of a direct current generator of constant voltage the greatest power output occurs when the internal resistance equals the external.

**480. Various Types of Amplifiers.**—Amplifiers may be divided into two classes :—

(*a*) **High Frequency Amplifiers.**

(*b*) Low Frequency Amplifiers, or **Note Magnifiers.**

**High Frequency Amplifiers** take a very weak signal, increase it up to an audible strength, and then apply it to the detector —crystal or valve—that is being used.

They are chiefly used in combination with a small aerial as used in submarines, direction finding sets, &c., so that the small aerial with an amplifier is the equivalent of a large aerial without one.

They may also be used in combination with a large aerial, to enable drastic methods to be employed for dealing with interference.

By the use of the various methods for achieving selectivity, all currents in the aerial, whether due to the required signal or to interference, may be reduced right down till there remains only the required signal, which may then be amplified up until it is at a convenient strength for reading.

It should be remembered that it is useless to amplify a weak signal unless the strength of interference is so much below that of the required signal that the result will be intelligible.

**481. Note Magnifiers** are applied to a signal that has already been rectified and is approaching audibility, and increase it so as to produce a loud sound in the telephones.

They are used whenever it is desired to make the sound in the telephones unusually loud in order to overcome local noises, such as gunfire, or drawing-room conversation.

Note magnifiers are not suitable for rendering really weak signals audible, although it is quite possible.

The detecting efficiency of a valve arranged to function properly as a rectifier varies roughly as the square of the signal strength, so that it is preferable to amplify very small signal voltages before rectification rather than after it.

It might, therefore, be thought desirable to carry out all amplification at high frequency, but the design of high frequency amplifiers is beset with many difficulties that are not nearly so serious in the case of note magnifiers.

When, therefore, considerable amplification is required, it is found convenient to carry out part of the operation before rectification, and part after it.

**482. Difficulties met with in Design.**—It is an easy matter to design an amplifier to work on one particular wave-length.

The ideal amplifier, however, is one that amplifies well over a wide band of wave-lengths, and works as well for spark, I.C.W. or radio-telephony as for continuous waves.

The following difficulties are met with :—

(*a*) **Control of Reaction.**—It is desirable to be able to use regenerative amplification for damped waves, but the reaction must be readily controllable; otherwise we may find the amplifier heterodyning at moments when a continuous oscillation is not required (*see* para. **490**).

Conversely, if we do not want to use a separate heterodyne, the amplifier must be provided with some method of establishing a heterodyne oscillation whenever this may be required for the reception of C.W. signals.

(*b*) **Simplicity of Adjustments.**—The amplifier must be simple to handle, and have few adjustments. An instrument which gives excellent results in the hands of an expert working in a laboratory, or when used on a fixed wave in a shore station, may prove quite useless for ship use.

(*c*) **Equal Amplification over full range.**—An amplifier must operate equally well over the full range for which it is designed. An instrument which amplifies one particular frequency much better than any other is termed "peaky," and is to be avoided as a rule, in view of the wide range of waves used in Naval working.

(*d*) **Avoidance of Capacitive By-paths.**—A difficulty met with in all amplifiers, and particularly in those used for very short waves, is the necessity for avoiding cross-coupling due to capacity effects.

These capacity effects occur—

(i) between the various leads inside the amplifier,
(ii) between the electrodes of the valves themselves.

It must be remembered that a condenser offers small impedance to a high frequency current; *e.g.*, the reactance of a condenser of 0·5 jar to a wave of 100 metres is only 600 ohms. Consequently, if there are a number of capacitive paths inside the amplifier, a high frequency current may pass right through an amplifier and hardly cause any variations in the valve currents at all.

A second undesirable result of capacitive paths in the amplifier is that reaction is thereby introduced. The oscillatory current in the output circuit is enabled to influence the input circuit and may set it in oscillation. This will be referred to again later.

(*e*) **Inter-Electrode Capacity.**—As regards the inter-electrode capacity referred to above, it might seem as though this would be so small as to be negligible, but such is far from the case; the internal capacity of a valve may have a great effect on its operation, especially at high frequencies.

There are three capacities to be considered, viz., filament to grid, grid to anode, and grid to filament and anode connected together.

The last condition is the most important.

Part of the internal capacity is in the actual working parts of the valve, but a lot of it is in the lead-in wires, where they come close together in the seal.

The base into which the valve fits also has appreciable capacity.

The capacity of an ordinary valve when in operation may be of the order of 60 centimetres (0·06 jar).

For this reason it is desirable to design the valves specially for amplifiers, with as low a capacity as possible;

this means making the area of the grid as small as is feasible, and keeping the wires connected to the grid as far from the wires leading to the anode and filament as possible.

**483. Methods of Coupling Valves.**—Amplifiers are usually classified according to the intervalve system employed in them. The object of this system is the same, no matter what type be employed, viz., to transfer a wave-form from one valve to another.

Amplification is produced by the combination of valve and intervalve system, and the necessary energy for the magnification is drawn from the high tension battery.

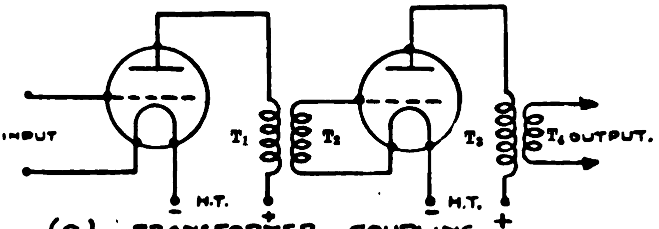
The following types are usually employed in high-frequency amplifiers :—

(*a*) Transformer.
(*b*) Tuned Transformer.
(*c*) Choke and capacity.
(*d*) Tuned Choke and capacity.
(*e*) Resistance and capacity.

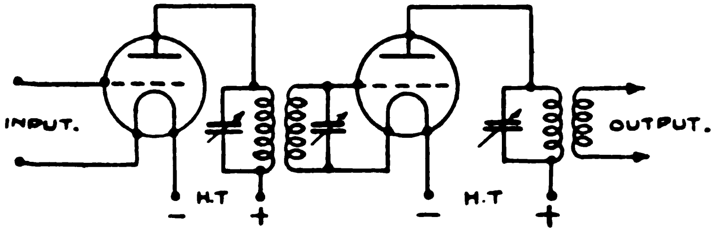
To any of these reaction may be applied if required.

Types (*a*) and (*c*) may have resistance deliberately inserted to make the amplifier less selective and to prevent the generation of oscillations.

**484. Transformer Coupling.**



(a) TRANSFORMER COUPLING.



(b) TUNED TRANSFORMER COUPLING.

FIG. 259.

Fig. 259 (*a*) shows simple transformers in use for inter-valve coupling, and Fig. 259 (*b*) the transformers tuned to resonance by the addition of condensers.

The sketch is simplified by the omission of the filament heating circuit, as it is only intended to illustrate the principle under discussion. A complete wiring diagram is given later.

Taking Fig. 259 (*a*), it can be seen that any voltage variation between the input terminals will cause a current variation through the primary ($T_1$) of the first intervalve transformer.

This will cause a voltage variation across the secondary ($T_2$) which will be applied between grid and filament of the second valve, and so on.

Now in the transformer there will be self-capacity (*a*) between the turns of the primary, (*b*) between the turns of the secondary, and (*c*) between primary and secondary.

Thus, as both primary and secondary possess capacity and inductance, they will be naturally in resonance with one particular frequency which they will amplify best.

In order therefore to make them suitable for amplification over a wider band of wave-lengths, and to avoid a " peaky " effect, it may be desirable:

(*a*) to join a condenser across both sides of the transformer (as in Fig. 259 (*b*) ).

(*b*) to provide several tapping points, so that the inductance of both primary and secondary may be varied.

These additions, however, increase the complication of the circuit and make tuning a slow process, unless we can so arrange matters that one handle adjusts the condensers, and another handle alters the transformer tappings, simultaneously.

An alternative method of avoiding a " peaky " effect is to destroy resonance deliberately by winding the transformers with high-resistance wire, so that their resistance is great compared with their reactance.

The loss in amplification may then be compensated for by adding more valves in cascade than would otherwise have been required.

The transformers usually have an equal number of turns in the primary and secondary windings, which are generally wound either side by side or one over the other on a former of insulating material. The usual iron-core would be unsuitable, as the losses due to the high frequency currents would be prohibitive.

For long wave-lengths, *i.e.*, low frequency currents, however, very thin iron sheets, or—better still—iron dust, are sometimes used in the core.

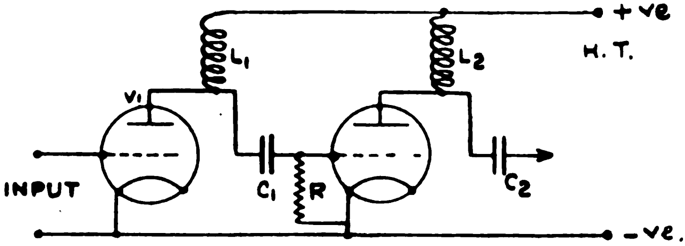
It might be thought desirable that the transformer should be a step-up one, having more secondary turns than primary.

A transformer used for high frequency currents, however, does not follow the ordinary laws, and energy is transferred across it as much by the capacity between the windings as by inductive action.

It would be found that the addition of more turns to the secondary would not increase the transformation ratio materially, while the additional self-inductance of the secondary would complicate tuning.

Transformer coupling is the best for amplifiers intended for use on very short wave-lengths, as the inductance present can be used to a certain extent to balance the self-capacity between leads.

### 485. Choke-Capacity Coupling.



*Choke capacity coupling.*

FIG. 260.

Fig. 260 illustrates a form of coupling in which the current variation in the valve $V_1$ passes through a coil $L_1$ of high inductance, *i.e.*, possessing a high reactance at the frequency at which the amplifier is used.

The voltage induced across $L_1$ by any change of current through it is applied to the grid of the next valve $V_2$ through the condenser $C_1$, which is provided to insulate the grid from the steady potential of the high tension battery; this would otherwise give the grid of the second valve a potential equal to that of the anode of the first valve, whereas we require the second grid to have a mean potential in the neighbourhood of zero volts.

The capacity of the grid condenser should be such that its reactance to the high frequency current is small, *e.g.*, a value of ·2 jar would have a reactance of 1,400 ohms to a wave of 600 metres, and would be quite suitable.

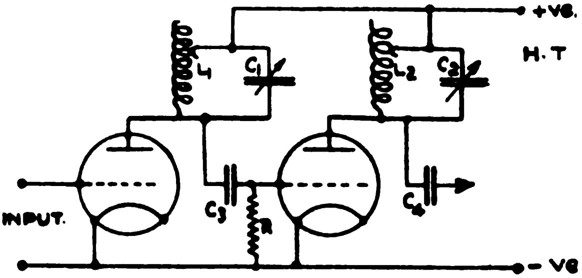
The smaller the condenser the more impedance will it offer to low frequency current impulses due to local noises such as inductive effects from the battery-charging leads.

The longer the wave the larger the condenser that must be used.

The grid leak R is made necessary by the presence of the insulating grid condenser C, and is for the usual purpose of preventing an accumulation of negative charge on the grid of the valve. It will be remembered from the preceding chapter that any grid which is insulated by a condenser always requires a grid leak to prevent it accumulating upon itself such a negative charge that the valve current is completely stopped.

In most amplifiers the leak resistance is in the neighbourhood of 1 to 5 megohms.

### 486. Tuned-Choke Coupling.



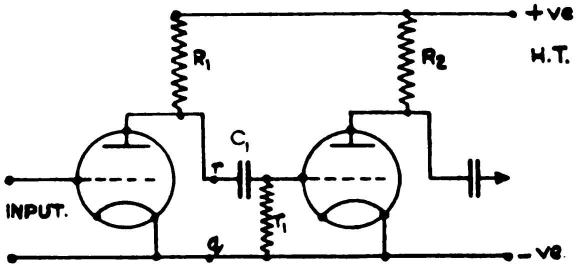
*Tuned Choke Coupling.*

Fig. 261.

An alternative to using a large inductance in the choke coil is to tune it to resonance with the help of a condenser, as in Fig. 261; it will be necessary also to make the value of the inductance adjustable if the amplifier is required to cover a wide range of wave-lengths.

This arrangement has the advantage that when tuned to a particular frequency it will amplify that one better than any other, and so a degree of selectivity is obtained.

### 487. Resistance-Capacity Coupling.



*Resistance-Capacity Coupling.*

Fig. 262.

In this type the choke coil shown in Fig. 260 is replaced by a resistance $R_1$.

All the anode current has to pass through $R_1$: when therefore any voltage variation is impressed across the input terminals there will be a current variation through $R_1$, and therefore a variation in the voltage drop across it. Since the voltage of the H.T. battery remains constant, the voltage variation will be felt between the points q and r, and will be impressed between grid and filament of the second valve, passing through the blocking condenser $C_1$. The process will be repeated in the next valve $V_2$ and so on.

The value of the resistance $R_1$ will be equal to or greater than the internal resistance of the valve—generally of the order of 20,000 ohms.

The condenser $C_1$ is provided to insulate the grid of the valve $V_2$ from the voltage of the H.T. battery, and the resistance $r_1$ to drain away negative charges from the grid, as before.

As the resistances $R_1$, $R_2$ will cause a big drop in the voltage of the H.T. battery, the latter must have a higher voltage than in the case of the amplifiers previously described. If the resistance used is equal to the internal resistance of the valve, the battery voltage will have to be twice that which would be required if the resistance were not there.

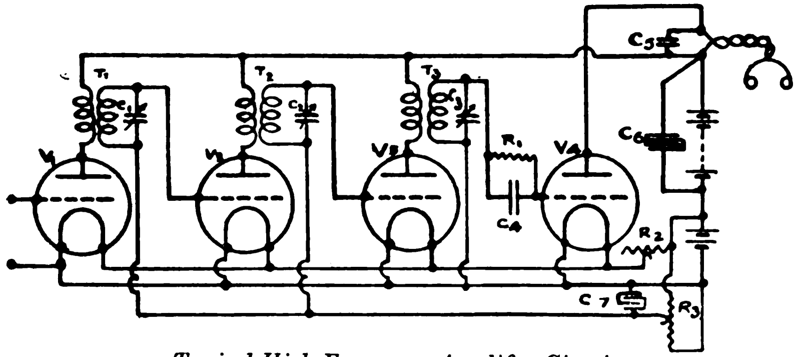
Resistance-coupled amplifiers are unsuitable for short wavelengths. This is because they have a good deal of unavoidable internal capacity, both between leads and in the valves themselves, while they have no inductance which can be used to balance the capacity reactance, as in the previous cases.

Their chief merit is that they avoid the use of tuned intermediate circuits, which require careful adjustment.

**488. The Rectifier.**—The last valve in high frequency amplifiers is used for rectifying purposes. If cumulative grid rectification (*see* para. **464**) is employed, a grid condenser and leak will be provided.

If not, it will be advantageous to provide a separate filament rheostat and grid potentiometer, so that this valve can be adjusted to the best condition for rectification, independently of the amplifying valves.

**489. The Amplifier complete.**



*Typical High Frequency Amplifier Circuit.*

FIG. 263.

Fig. 263 is inserted as an illustration of a typical high frequency amplifier.

The three valves $V_1$, $V_2$ and $V_3$ act as high frequency amplifiers, and $V_4$ as a rectifier.

The valves are coupled by the transformers $T_1$, $T_2$, $T_3$, whose secondaries are tuned by the condensers $C_1$, $C_2$ and $C_3$.

The grid potentials of the first three valves can be made more or less positive by means of the potentiometer $R_3$, which is connected across the filament battery terminals.

The rheostat $R_2$ controls the filament current of all the valves in parallel.

In order to provide for cumulative rectification, the condenser $C_4$ and leak $R_1$ are connected to the grid of valve $V_4$.

The condenser $C_5$ (capacity 4 jars) provides an easy path for high frequency current, while the condensers $C_6$ and $C_7$ (capacity 2 microfarads) are put in shunt with the amplifier batteries and the grid potentiometer respectively, to carry both radio- and audio-frequency variations.

**490. Prevention of Oscillations.**—One of the greatest difficulties in the design of amplifiers, as previously mentioned, is to prevent the establishment of unwanted heterodyne oscillations.

If such an oscillation sets in when spark I.C.W., or R/T are being received, the quality of the note or speech is completely spoilt.

On the other hand, it is desirable that regenerative amplification, whereby the circuit is brought to the point when it is just **not** oscillating, should be possible when receiving damped waves, and alternatively that the circuit may be used as an *auto*-heterodyne for C.W. signals if a separate heterodyne is not provided.

Several methods are in use for avoiding unwanted oscillation, but most of them result in a reduction of amplification.

The methods most commonly used are as follows :—

(*a*) Spacing the leads, etc., well apart, so as to avoid cross-coupling.

(*b*) Separating portions of the amplifier from one another by earthed metal screens. This leads to a loss of energy, through eddy currents induced in the screens.

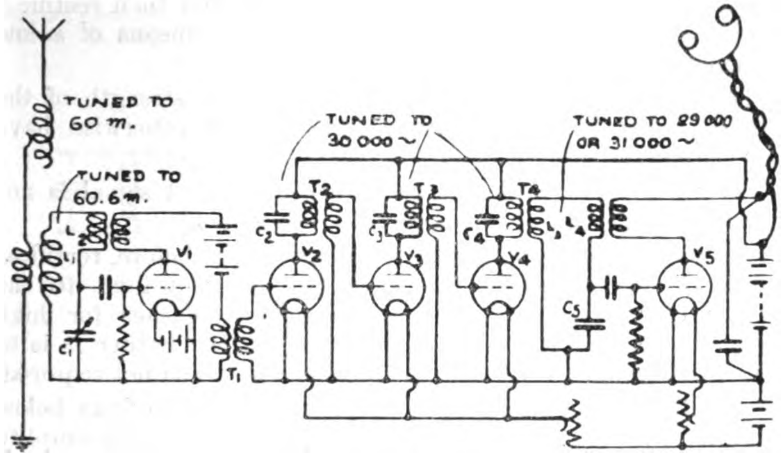
(*c*) The reduction of filament current or anode voltage. This also leads to a reduction in amplification.

(*d*) The use of positive potential on the grids of the amplifying valves. This leads to heavy grid currents, and the effect is termed "grid damping." Since the presence of grid currents mean the reduction in amplitude of the positive half cycles of the wave (*see* para. **460**), the amplification per valve is again decreased.

(*e*) The use of "negative reaction." A reaction coil, or coupling condenser, may be connected so as to prevent the generation of oscillations instead of assisting it.

(*f*) The reduction of the ratio L/C in tuned circuits.

## 491. The Armstrong Short Wave Circuit.



*Armstrong Short-wave Circuit.*

FIG. 264.

An ingenious circuit for amplifying short waves is illustrated in Fig. 264.

Suppose we wish to receive a wave on 60 metres (5,000 kc.). The aerial circuit will be tuned to this wave. The autodyne circuit $L_1$, $L_2$, $C_1$ is tuned, by the Condenser $C_1$, so as to have a difference in frequency of **30,000 cycles** with the incoming waves. To give this result, the circuit should be tuned to 5,030 or 4,970 kc. (59·64 or 60·36 metres). This will give a beat frequency of 30,000 cycles, which will be rectified on the grid of the first valve $V_1$ and will reappear in the anode circuit.

Then come three valves, $V_2$, $V_3$, $V_4$, whose anode circuits are all tuned to a fixed frequency of 30,000 cycles.

Consequently the rectified beat frequency, in passing through the valves $V_2$, $V_3$, $V_4$ and intervalve transformers $T_1$, $T_2$, $T_3$ is considerably amplified, while interference from waves of (say) 65 or 55 metres will produce a different beat frequency in the circuit $L_1$, $L_2$, $C_1$, and will consequently not be amplified at all.

The last circuit, viz., $L_3$, $L_4$, $C_5$, is tuned to a fixed frequency of 29,000 or 31,000 cycles, and is provided with reaction so as to maintain a continuous oscillation. Thus the frequency of 30,000 cycles is heterodyned to produce a beat at 1,000 cycles which is rectified on the grid of the valve $V_5$ and passed through the telephones.

The advantages of this circuit are

(*a*) the difficulties that would be involved in designing an amplifier for this short wave are avoided.

(*b*) The circuit is very selective.

(*c*) The adjustments are very simple, as only the aerial circuit, and the grid circuit of the first valve, have to be adjusted.

**492. Note Magnifying.**—After the signal has been amplified at high frequency, to a reasonable strength, and then rectified, its strength may be increased still further by means of a **low frequency amplifier** or **note magnifier.**

This denotes an amplifier for increasing the strength of the low frequency current impulses which would otherwise have been passed directly through the telephones.

Its use may be desirable because the rectified signal is not already loud enough to be read over local noises.

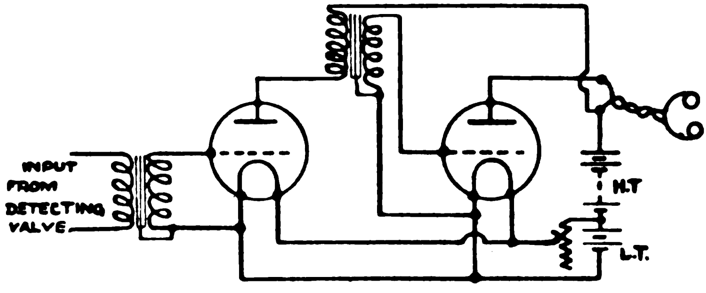
The additional amplification after, instead of before, rectification is desirable for the reason that there is a limit to the number of valves that can be connected together for high frequency amplifying, as the more there are the harder it is to prevent self-produced oscillations being set up when not required.

It is therefore preferable to amplify a signal up from below audibility to a certain value, rectify it, and then again amplify it at low frequency.

**493. Methods of Coupling Note Magnifiers.**—Valves used for note magnifying are coupled together as before by—

(*a*) Transformer coupling.
(*b*) Choke-capacity coupling.
(*c*) Resistance capacity coupling,

to the first two of which a tuning condenser may be added.



*Transformer-Coupled Note Magnifier.*
FIG. 265.

A transformer-coupled note magnifier, as illustrated in Fig. 265, differs from a similar high frequency amplifier in two particulars :—

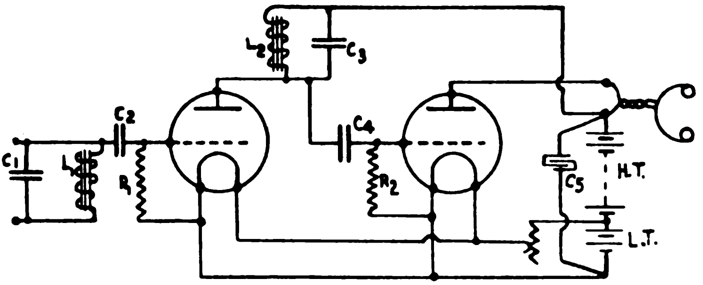
(*a*) Iron cores are used in the transformers.

(*b*) Step-up transformers may be used, with a ratio of as much as 1 : 5.

It will be noticed that the iron cores of the transformers are connected to the transformer secondary terminal which is connected to the filament battery.

The effect of this is to annul capacity effect between the core and the secondary winding, and to decrease self-oscillation of the note magnifier circuit at audible frequency.

### 494. Choke-Capacity Coupling.



$C_1\ C_3 = 1$ Jar. $C_5 = 2\ \mu F$.
$C_2\ C_4 = 90$ Jars. $L_1\ L_2 = 32$ H.
$R_1\ R_2 = \cdot 5\ M\Omega$.

*Tuned-Choked-Coupled Note Magnifier.*

FIG. 266.

Fig. 266 illustrates a choke-capacity-coupled note-magnifier.

The chokes are provided with iron cores, and their inductances in the circuit illustrated are 32 henries.

The natural frequency of these chokes, in combination with the 1-jar condensers joined across them, will be found to be 850 cycles; this will be the frequency at which the greatest amplification is given.

The condensers $C_2\ C_4$ are of much larger capacity than in the case of the high frequency amplifier, as they have to offer small impedance to audio-frequency current variations.

**495. Resistance-Capacity Coupling.**—A resistance-capacity coupled note magnifier is similar in arrangement to Fig. 266, resistances being substituted for the circuits $L_1\ C_1$ and $L_2\ C_3$.

The principle of operation is exactly as described in para. **487** above, and needs no further explanation.

**496. Connection from Detector to Note Magnifier Circuit.**—It is important to notice that, in separate note magnifiers, whatever the inter-valve system employed, the first stage inside the box is intended to be the inter-valve coupling between the detecting valve and the first valve of the note magnifier; as such this coupling should be connected direct between the anode of the detecting valve and the positive of the anode battery. The introduction of a telephone transformer or condenser in the anode circuit of the detecting valve may reduce the efficiency of the note magnifier.

Modern service note magnifiers designed to share common batteries with other models have only one input terminal, which is connected to the anode of the detecting valve, and the circuit is completed through the common anode battery.

**497. Limiting and Balancing.**—A difficulty involved in the use of amplifiers is that atmospherics and other loud interference are liable to get amplified up also, and to drown the required signal.

This trouble is minimised in two ways, namely, by causing a "limiting" and "balancing" action to take place at the detecting valve.

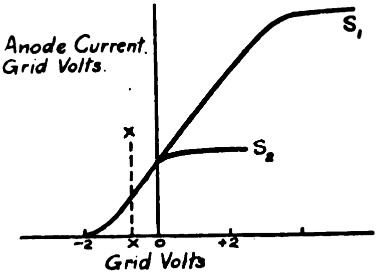


Fig. 267.

**Limiting.**—By "limiting" is meant that it is possible to cut down a strong interfering signal without affecting the strength of a weak signal. The latter may therefore be made readable by so doing.

For this purpose a separate filament rheostat and grid potentiometer are provided for the detecting valve.

The action is as follows :—

Suppose $S_1$ (Fig. 267) to be the saturation anode current of the detecting valve when burning at normal brilliancy.

If now the filament current is reduced by means of the rheostat until the saturation current $S_2$ is given it is evident that no signal, however loud, will give a greater strength than that represented by the curve $S_2$, for this is the maximum amount through which the anode current, and hence the telephone current, can vary.

This should enable the weak signal to be read over the stronger signal, if the notes are distinctive, and should be of great help in dealing with atmospherics.

**Balancing.**—By "balancing" is meant an adjustment by which a weak signal is rectified and made audible, while one slightly stronger is not rectified and is therefore not made audible.

This is the more important effect of the two.

Let us suppose that the filament current is reduced by means of the rheostat till the maximum filament emission is 200 microamps., as in Fig. 268, and that the grid potentiometer is adjusted to a negative value of 1 volt, as indicated by the line XX.

Let us suppose that two waves are applied between grid and filament, the first of which varies the grid potential ± ·4 volt, and the second ± 2 volts.

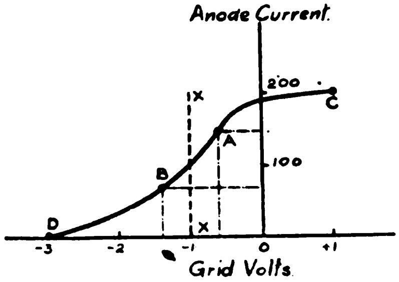


FIG. 268.

The first wave will vary the grid potential between the points A and B, giving an increase of anode current during the positive half-cycles of 100 to 150 microamps.—an increase of 50 microamps.—and a decrease during the negative half-cycles of 100 to 70—a decrease of 30 microamps.

This gives a rectification for each cycle proportional to 50—30 = 20 microamps.

The second wave will vary the grid potential between the points C and D, giving an increase of 100 to 200, and a decrease of 100 to zero.

This gives no rectification at all.

Thus the weak signal will be rendered audible and the stronger one inaudible.

**498. Handling of Amplifiers.**—In order to get full value out of an amplifier, an operator must use his intelligence over each adjustment he makes.

An amplifier is not given him so that he can read signals with the telephones on the table. The minimum possible amplification should be used, so as to avoid waste of valves, telephones, and battery power.

In order to reduce interference, all receiving circuit adjustments must be set to the most selective condition possible. This will weaken the desired signal somewhat, so the amplifying valves must be carefully adjusted by filament rheostat and grid potentiometer; if possible, use should be made of regenerative amplification.

The detecting valve is frequently given separate controls for its filament current and grid potential, and it is often found that interference can be cut out by dulling the filament slightly and readjusting the grid potential.

As regards the grid potentiometer of the amplifying valves, a good general rule is to use positive grid potential for spark, I.C.W. or R/T signals (to avoid self-oscillation) and negative potential for C.W.

Briefly stated, the reason for this is that the more positive the grid is made the greater is the grid current, and hence the less the grid-filament resistance of the valve.

Any decrease in grid-filament resistance will increase the damping in an oscillatory circuit connected between grid and filament, and hence render the setting up of oscillations more difficult.

Trouble is often caused by using filament batteries which have nearly run down. The valves appear to be burning correctly, but amplification is poor.

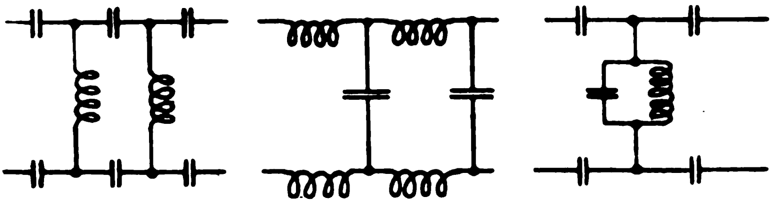
The battery voltage should be occasionally checked by the voltmeter provided.

**499. Amplifier Noises.**—If the process of amplification is carried too far, or if an amplifier is badly designed, it will be found that many interfering noises will be heard in the telephones.

These noises may be classified as follows :—

| Symptom. | Cause. |
|---|---|
| (1) **Valve Noises.** | |
| (*a*) Frying noises - - | Soft valve. |
| (*b*) Intermittent noises like atmospherics. | Bad filament. |
| (*c*) Clicks - - - | Loose contacts. |
| (2) **Bad Design.** | |
| (*d*) External noises easily picked up. | Unscreened transformers. |
| (3) **Howling, &c.** | |
| (*e*) Howling in case of a note magnifier. | Continuous oscillation of a low frequency circuit due to cross coupling. |
| (*f*) Howling in case of a high frequency amplifier. | Generation of two high frequency oscillations giving an audible beat. |
| (*g*) A steady succession of clicks. | The result of using a grid leak of too high resistance.<br>A self oscillation piles up a negative charge on an insulated grid faster than the leak can drain it away; the oscillation then stops momentarily and starts again as soon as the negative charge has drained off. |
| (4) Battery Trouble. | |
| Crackling noises - - | Loose contact, or defective cells in H.T. battery. |
| (5) Induction from Mains. | |
| Continuous hum - - | Leads to battery on charge too near leads from battery in use. |

**500. Filter Circuit.**—The term "Filter Circuit" is used loosely to cover any type of circuit used in conjunction with an amplifier to remove undesired frequencies and thus give selectivity.



*Filter to pass High Frequency.*

(i)

*Filter to pass Low Frequency*

(ii)

*Filter to pass one particular Frequency.*

(iii)

Fig. 269 (*a*).

If it is desired to eliminate low frequency interference the circuit shown in Fig. 269 (*a*) (i) may be used. Here high frequency currents will pass readily through the condensers, while low frequency currents will find the condensers a path of high reactance, and will prefer the short-circuit path through the inductances.

Fig. 269 (*a*) (ii) indicates the opposite type of circuit, namely, one designed to pass low frequency or direct current, and impede the passage of high frequency current.

If designed to pass direct current only, as when joined up in the D.C. source of supply to a valve receiver, the inductances will have iron cores, and the condensers will have values of the order of microfarads.

The circuit shown in Fig. 269 (*a*) (iii) includes a rejector circuit tuned to a particular frequency. Current at this frequency will therefore be unable to pass through it, and must pass along the line as required.

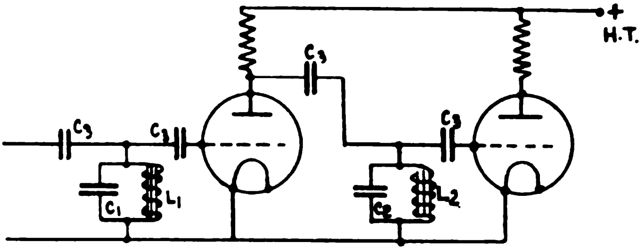
Currents at other frequencies will find an easy short-circuit path through the rejector.

The filter must be terminated by the correct impedance, which is determined by the ratio of the capacities and inductances used.

**501. Note Filter Circuit.**—A "Note Filter" or "Note Selector" circuit is used to add a further degree of selectivity, by allowing **audio-frequency** currents of one particular frequency only to pass through the telephones.

This application is of great importance. It makes possible the operation of several different channels of communication on the same wave-length, using I.C.W. with different modulating frequencies.

Fig 269(*b*) illustrates a typical circuit. It represents a combination of a note magnifier circuit with rejector circuits $L_1$ $C_1$ and $L_2$ $C_2$.



*Note-Filter Circuit.*

FIG. 269 (*b*).

The heterodyne in the high frequency stage of the receiving gear is adjusted to give a note in combination with the required signal of the same frequency as that to which the rejector circuits are tuned.

This signal will therefore suffer no loss in the rejectors, and will be magnified and passed through the telephones in the usual manner.

Signals of other frequencies, however, giving other notes in combination with the heterodyne oscillation, will find a short-circuit path through the rejector circuits $L_1$ $C_1$ and $L_2$ $C_2$, and should not reach the telephones at all.

## CHAPTER XIII.

## TRANSMITTING VALVES AND VALVE TRANSMITTING CIRCUITS.

**501.** Transmitting valves are used in exactly the same way as receiving valves for generating a continuous high frequency oscillation, but this oscillation is used to energise an aerial for transmitting purposes.

A transmitting valve is like an enlarged receiving valve.

The filament is a loop of tungsten or thoriated tungsten wire with the end of the loop held taut by a special spring.

The grid is made of molybdenum wire, and is spiral in shape.

The anode is cylindrical, and is made of nickel or molybdenum.

**502.** The difficulties met with in the design of a transmitting valve are altogether different from those of a receiving valve.

The chief difficulty is in connection with the radiation of heat from the anode and envelope.

The electron current arriving from the filament will always tend to heat up the anode considerably when the anode voltage is high. Hence a sufficient area of anode must be provided to radiate this heat away.

The hotter the anode the greater the power radiated per unit area; or, to radiate a given power, the hotter the anode the smaller the area necessary.

Most metals, however, are liable to "occlude," or drive some gas out of their pores when they are heated; if this gas is given off it softens the valve unduly and deteriorates it.

Hence it is of advantage to use a metal which can be taken up to a considerable temperature without melting or giving off gas.

Nickel and molybdenum are used at present, the latter being the best.

When the valve is being pumped out, the whole anode must be raised to near the melting point; in practical use afterwards it must not be taken as far as this; then no more gas comes out.

In the same way, the envelope of the valve has to get rid of the heat produced at the anode.

Transmitting valves are rated by the power that the anode is capable of dissipating on full load—*i.e.*, so many watts or kilowatts.

Under efficient conditions about 66 per cent. of the power taken from the supply is expended in the oscillatory circuit, and the remainder on the anode of the valve.

For any given set the actual proportion expended depends entirely on the efficiency and design of the oscillatory circuit as a whole.

The valve current which when multiplied by the anode voltage gives the power for which the valve is designed, is known as the "**emission current.**"

This value is always marked on the valve box, and should be adhered to; it generally rises somewhat, however, after the valve has been in use some time.

The "**saturation current,**" as before, is the maximum electron current which the filament can emit for the particular temperature to which it has been raised.

**503.** Three types of envelope are used for containing the electrodes—viz., glass, silica and metal.

**Glass Envelopes** are as a rule only suitable for valves intended to handle powers up to about 500 watts, though special forms of glass are sometimes used for higher powers.

Above this power the size of the envelope required and the difficulty of keeping it sufficiently cool render the use of silica or metal desirable.

The energy developed at the electrodes radiates away in the form of (*a*) ultra-violet rays (*b*) visible light rays (*c*) infra-red rays (*see* Table VI., p. 6).

Now glass is transparent to aether waves of the frequencies of visible light but opaque to those immediately above and below. Hence the glass envelope will absorb the radiated heat and will become very hot: the permissible rise of temperature limits the power which the valve can handle. **Silica,** on the other hand, has the property of being transparent to a far wider range of aether waves, and consequently passes the great majority of the radiated energy without itself becoming heated: the energy of the heat waves is dissipated in heating up the surrounding air instead of the envelope of the valve.

**504. Silica Envelopes.**—Silica is simply fused quartz.

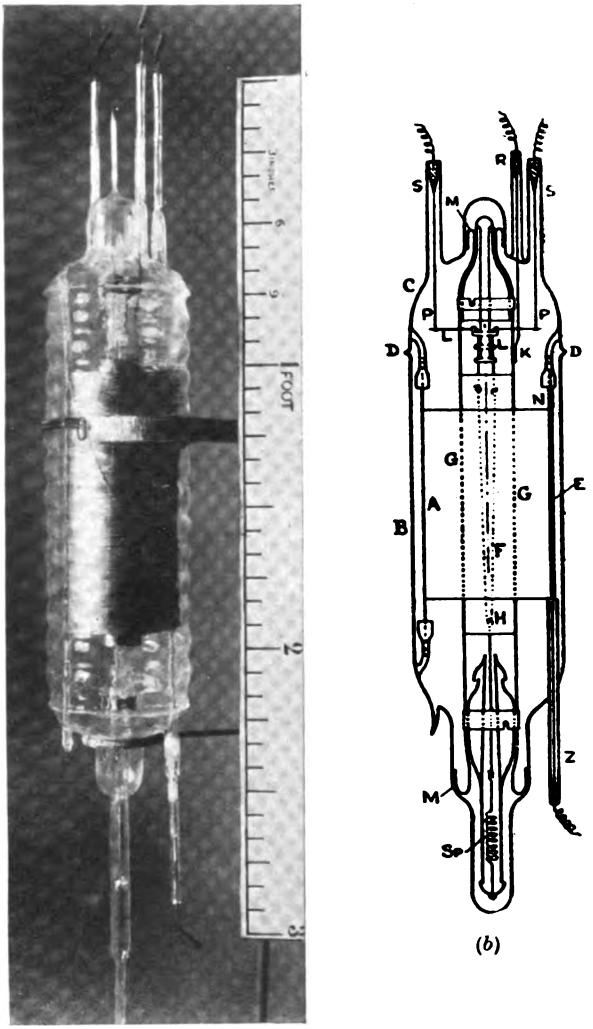
The appearance and construction of a typical silica valve are illustrated in Fig. 270.

Silica has two great advantages as compared to glass:—

(*a*) As explained above, the envelope does not become unduly heated from the energy developed at the electrodes.

(*b*) It has a very low co-efficient of thermal expansion. This means that it can be suddenly heated and cooled without cracking. This is a great advantage in the process of manufacture, and permits the making of very complicated mechanical designs which would be quite impossible with glass.

Further, it is frequently desired to open up the envelope in order to replace electrical parts such as a burnt-out filament, and with silica this opening up can easily be accomplished by means of simple rotary tools such as those employed by dentists, the re-sealing being accomplished by means of the oxy-hydrogen blow-pipe.



(b)

(a)

*Appearance and construction of Silica Valve.*

FIG. 270.

| | |
|---|---|
| **A.** | **Anode.** |
| **B.** | **Body of envelope.** |
| **C.** | **Cap of envelope.** |
| **D.** | **Flange where cap and body are joined.** |
| **E.** | **Anode connection, joined to anode at N so that anode can easily be removed when envelope is opened by cutting open the flange D.** |
| **F.** | **Filament, connected by molybdenum wire hook H.** |
| **Sp.** | **Filament tensioning spring, carried in a silica insulator.** |
| **G.** | **Grid.** |
| **M.** | **Extensions of grid framework sprung into the silica tubes.** |
| **L.** | **Filament end pieces, resting in hooks on the silica insulator so that the filament can easily be renewed.** |
| **Z.** | **Anode seal.** |
| **R.** | **Grid seal, internal connection bound to grid at K.** |
| **S.** | **Filament seal, internal connection bound to filament end pieces at P.** |

**Sealing-in of Connections.**—In the case of electrical connections through glass, advantage is taken of the fact that the co-efficient of expansion of platinum is approximately the same as that of glass, and consequently an air-tight seal is easily made in glass by means of platinum wire. With silica, however, this circumstance is not available, and the method used is the employment of molybdenum wire sealed into a silica tube by means of a long seal of **lead.** As the wire heats the lead softens and forms, in fact, almost a fluid seal.

**505. Metal Envelopes.**—As the power demanded from valves has increased, the problem of keeping the anode cool at very high emissions has become more important. To meet it valves have been constructed in which the anode, instead of being contained by, actually constitutes the envelope and can be cooled by means of circulating water. The function of the glass then is only to form the insulation of the leads to the grid and filament systems.

The principal difficulties presented by the introduction of this type of valve are, firstly, the seals between the metal and glass, and, secondly, the fact that metal holds occluded gas to a far greater extent than either glass or silica.

Copper and allied metals such as nickel have the convenient property of being "wetted" by molten glass, and therefore adhere to it on cooling; this allows of a joint being made between the two substances. The coefficients of expansion of glass and copper are, however, very different, and so under ordinary conditions the joint would crack with change of temperature. To meet this difficulty, glass-to-copper joints are made in which the glass is welded to a sharp knife-edge bevel on the copper. The thinness of the metal at the edges will then be such that the necessary distortion of the joint with temperature change is attained without fracture of the glass. In this way a joint can be made between the two which will withstand change of temperature up to 300° C.

To get rid of as much of the occluded gas as possible before the valve is assembled, the anode—which is also the principal portion of the envelope—and the grid and filament systems are heated in vacuo; then, when the valve is put together, much less pumping is required to produce the necessary high vacuum. Prolonged heating after the valve has been assembled is liable to cause warping.

An advantage of metal valves lies in the fact that they can be conveniently water-cooled. As in the arc, the cooling water must be fresh and, in this case, as the jacket is at the voltage of the anode, which usually has a considerable high-frequency voltage to earth, the resistance of the water circuit is kept as high as possible by using long rubber pipes.

Experiments have been described on valves of this type up to 100 kW. anode dissipation and, in America, a valve capable of dissipating 1,000 kW. is talked of.

Another type of metal valve is the Holweck valve, with which a pump is continuously employed to maintain the vacuum. The valve is made in three main portions. These are the anode, which is of brass, the end pieces carrying the grid and filament system, and the connections for the pump, which are of glass and fit over the brass body. The glass-metal tapered joints are carefully ground together, and the whole is made vacuum tight by means of a special grease.

When first assembled the valve takes about an hour to exhaust, and the pump is kept running all the time the valve is in use. After use the vacuum can be restored in about one minute whenever required.

Valves up to 30 kW. have been constructed on this principle. The anode voltage is somewhat lower than that employed for the "sealed off" type described above, being about 8,000 V.

The Holweck valve compared with those which are finally sealed off has the advantage of having its vacuum more constantly maintained. Metal always gives off occluded gas to a small extent when heated, and the pump will drain this away as it appears; while, when no pump is fitted, the valve gradually softens. On the other hand, the necessity for a complete exhausting outfit and the time required to re-start after the valve has been out of use for some time are serious disadvantages.

**506. Characteristic Curves.**—Fig. 271 illustrates a typical anode current-grid voltage curve for a silica valve.

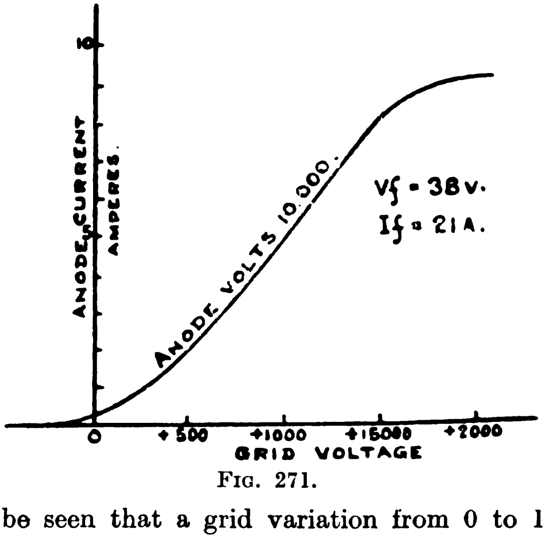


Fig. 271.

It will be seen that a grid variation from 0 to 1,500 volts will vary the anode current from 0·3 to 9 amperes.

**507. The Grid Current-Grid Volts Curve.**—Fig. 272 illustrates a typical grid current-grid voltage curve for a smaller transmitting valve.

Two curves are shown, for anode voltages of 100 and 700 respectively.

The curve for 100 anode volts is very similar to that of a hard receiving valve.

The curve marked " Anode Volts 700 " is inserted as a matter of interest. It will be seen that up to +40 grid volts the curve is fairly normal, but after that point the curve falls away and actually crosses the zero line.

The explanation is that after that point the electrons are travelling with such an enormous velocity, owing to the high grid voltage, that those hitting the grid drive out some more which move off to the anode.

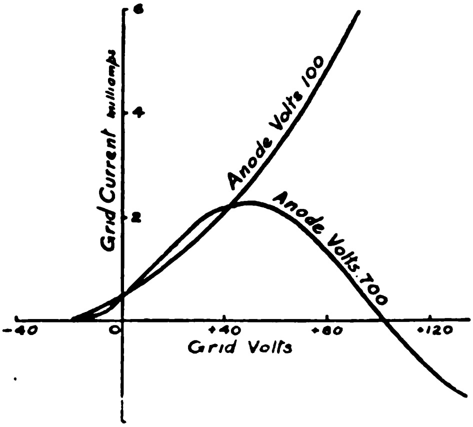


FIG. 272.

The grid current curve thus falls off, being a measure of the electrons being collected by the grid at any moment.

At + 104 grid volts the grid current curve is **zero,** because each electron arriving drives out another from the grid, so that the nett charge on the grid at any moment is zero, while after this point each electron arriving expels more than one other so that the curve becomes negative.

We have here a falling volt-ampère curve similar to that of the Poulsen arc.

This phenomenon is employed in the " dynatron " circuit.

**508. Circuit used.**—The simplest circuit for use with a valve transmitter is as follows (Fig. 273) :—

The oscillating circuit consists of the aerial capacity, in series with an aerial coil for tuning purposes; an aerial coupling coil for varying the grid potential in time with the oscillations of the aerial; and an aerial ammeter, for recording the oscillatory current in the aerial circuit.

The high potential supply is fed (through an **anode choke coil**) to the anode and filament of the valve, the valve being in parallel with the aerial circuit.

Between the anode and the aerial coil is placed the **anode blocking condenser,** which prevents a short circuit of the high potential supply through the aerial circuit.

The grid is coupled inductively to the aerial circuit, so that an oscillatory current in the aerial will vary the grid potential.

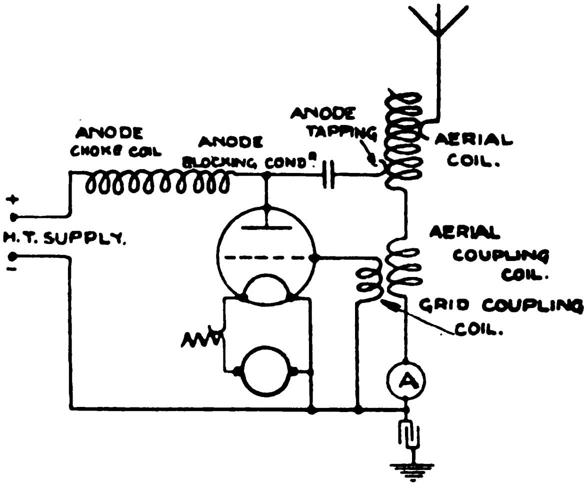


FIG. 273.

The filament is heated by current from a small motor generator, and this current is regulated by a suitable rheostat.

Alternating current may be used for the same purpose.

**509. Variation of Anode Potential.**—Before explaining the action of this circuit, we must examine carefully how the potential of the anode varies with a change in the grid potential, adopting a point of view different from that taken in Chapter XI.

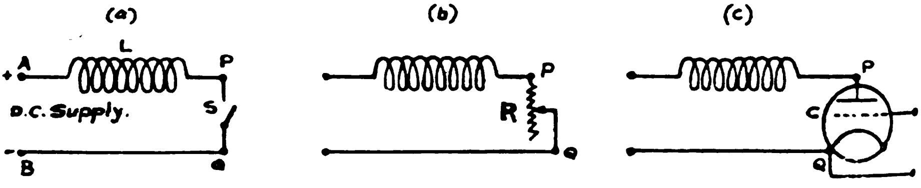


FIG. 274.

First consider the circuit shown in Fig. 274 (*a*), where L is a large inductance and S is a switch : a steady P.D. is maintained between the terminals A and B.

On closing the switch S a current will begin to flow from A round to B, and will reach a steady value equal to $\frac{V}{R}$ ampères.

Now if the switch S is suddenly opened, a large spark will occur, showing that the P.D. between P and Q has suddenly risen owing to the voltage induced in L by the sudden fall in current through it (Lenz' Law).

Taking a less extreme case, let us replace the switch by an adjustable resistance R (Fig. (*b*) ).

A **sudden** increase of R will reduce the current through L and will increase **momentarily** the potential of P with respect to Q.

Conversely, a **sudden** reduction of R will increase the current L and will give rise to a **momentary** reduction of the potential of P with respect to Q.

Now, let us replace R by the 3-electrode valve C (Fig. *c*).

We know that as the grid potential is made more negative the valve current is decreased, while if the grid potential is made more positive (or less negative) the valve current is increased. Thus the valve corresponds with the variable resistance R : an increase of negative grid potential being equivalent to an increase of R, and vice versa.

Hence, whenever the grid-filament potential is made more **negative,** the anode-filament potential will be **increased,** while when the grid-filament potential is made **less negative,** the anode-filament potential will be **decreased.**

**510. Action of Circuit.**—We are now in a position to investigate how an oscillation may be maintained in the circuit shown in Fig. 273.

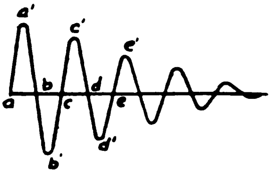


Fig. 275.

Let us assume that by the action of pressing the transmitting key the aerial is given a slight shock such as to set it in oscillation at its own natural frequency. If left to itself the oscillation would soon die away, as in Fig. 275, and **in order to maintain it** positive impulses should be applied between a and a′, b′ and c′, d′ and e′, and negative impulses between a′ and b′, c′ and d′, &c.

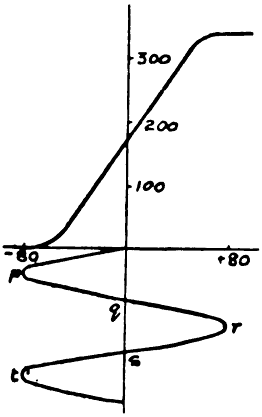


Fig. 276.

Now, at (*a*), Fig. 275, the grid potential will be zero, and the valve current (say) 173 milliamps. (Fig. 276). When the aerial current increases from a to a′ let us assume that the voltage induced on the grid through the grid coupling coil will be such as to take the grid potential out to the point " p " ( – 80 volts).

This will lead to a **rise** in anode voltage, and a **positive** impulse given to the aerial through the anode blocking condenser. Then. as the grid potential changes from " p " to " r " through " q," the anode current will **increase** from zero to its saturation value, and a **negative** impulse will be given to the aerial, due to the anode voltage falling, corresponding to a′, b, b′ on the aerial oscillation curve.

Similarly the alteration in grid voltage from " r " to " t " leads to a **fall** in the valve current, an **increase** in anode voltage, and a **positive** impulse applied to the aerial between the moments b′ and c′.

The positive and negative impulses given to the aerial by the valve are thus timed correctly to maintain the original aerial oscillation, which will thus be made **continuous.**

Hence the valve may be conveniently looked upon as a switch controlling an alternating voltage supplied to the aerial at a frequency determined by the aerial circuit itself.

The aerial oscillation thus started builds up quickly to a value depending on the one hand on the aerial damping losses, and on the other hand on the valve characteristics, the arrangement of the circuit, the filament current, and the high potential supply.

The reader should not allow himself to be confused by the presence of the anode blocking condenser; he should regard it as a bar to the D.C. supply, but a short circuit to the high frequency impulses from the anode.

Of course, the grid coupling coil must be joined up in such a manner that the changes in anode voltage are timed correctly to maintain the aerial oscillation; if not, the aerial will try and supply power to the valve instead of the valve supplying the aerial, and the oscillation will soon be damped out.

It will be seen that the duty of the **Anode Choke Coil** is not primarily to prevent any variations in the D.C. supply, but by its own self-induction to arrange for variations of anode potential with valve current.

Now, as has already been stated, any coil has a natural LC value of its own, due to its self-inductance multiplied by its self-capacity, and care must be taken that the LC value of the choke coil is considerably greater than those of any of the waves to which the aerial may be tuned.

Otherwise it will merely form a closed resonant circuit in tune with the aerial oscillation, and heavy currents will be set up in it which may burn it out.

**The Anode Tapping Point.**—It is in the nature of the valve as a generator of oscillations that it will always build up the aerial current until some limit is reached, and one limit is that the current will rise until the resulting variations of anode voltage are some value a little less than the D.C. volts applied.

Since the oscillatory anode voltage is equal to the voltage between the anode tapping point and earth (neglecting the voltage drop across the anode blocking condenser), we can say that the aerial current will rise to such a value as to make

$$\omega L I_a \text{ nearly equal to } V_{dc}$$

where L is the inductance below the anode tapping point, and $I_a$ is the aerial current.

If, therefore, we increase L, $I_a$ cannot rise so far. If we decrease L, $I_a$ will rise until we reach a point at which any further increase can only be given at the expense of an overheated anode.

The ideal anode tapping point is that at which maximum oscillatory current is given in the aerial without overheating the anode.

Suppose a value of L has been found which suits a particular frequency to which the aerial circuit is tuned, and suppose we now desire to increase the wave-length and therefore decrease the frequency, then since $\omega$ (= $2\pi f$) has been decreased, the value L must be **increased** to satisfy the above equation. In other words, the longer the wave-length, the higher up the aerial coil must the anode tapping point be placed, and vice versa.

In every case the best position is found by trial.

The **Grid** is inductively coupled to the aerial circuit. With a given valve and an aerial of given capacity, the grid coupling must be increased, the greater the inductance and the greater the damping of the aerial circuit; but, however, the tighter the grid coupling, the more of the available power will the grid itself absorb from the aerial circuit.

**511. Modification to the Simple Circuit.**—Two modifications to Fig. 273 are shown in Fig. 277 :—

(*a*) **Tuned Grid Circuit.**—A grid tuning condenser C is fitted in parallel with the grid coupling inductance.

This arrangement is used when a wide range of LC values is required in the aerial circuit.

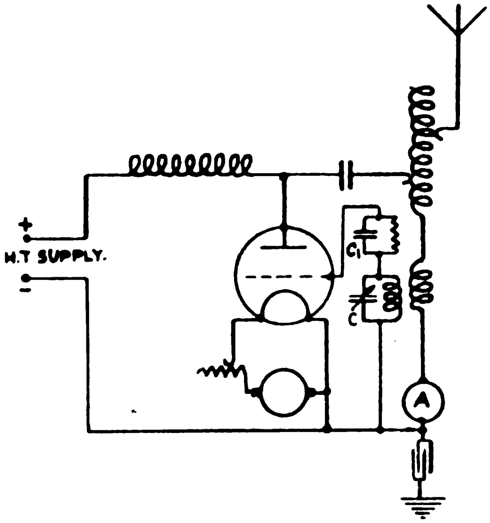
The reason for adding it across the coupling coil is that the big change of voltage required on the grid when a large LC value is being used in the aerial circuit can be easily built up if resonance is taken advantage of by adding a small condenser, whereas a larger **aperiodic** inductance would have to be used to give the same result.

In practice, the grid condenser is varied until—

(*a*) the aerial current is a maximum :
(*b*) the anode current is a minimum.

For this condition the grid circuit is **not quite** in resonance with the aerial circuit.

If it is exactly in resonance, the current in the grid circuit will be excessive, and will represent a large waste of available energy, while the variations in anode voltage will not be timed correctly for maintaining the aerial oscillation. This at first sight might appear to be a misstatement, but can be proved theoretically.



*Tuned Grid Circuit with Insulated Grid.*

Fig. 277.

(*b*) **The Grid Condenser and Leak.**—The grid is insulated from the filament by a condenser $C_1$, with a high-resistance rod across it, as in valve receiving circuits when the principle of grid rectification is employed.

**Action.**—If the grid is left **completely insulated** by the condenser, it will always be collecting, or rectifying, a certain negative charge on itself while an oscillation is going on in the aerial.

If a high resistance path is joined across this condenser the charge thus rectified will drain away at a rate depending upon the resistance of the leak, and the grid will be held at a potential **negative** to the filament equal to the voltage drop in the resistance.

Hence, by designing the leak suitably, the grid can always be kept at any **desired value of negative potential.**

The condenser $C_1$ affords an easy path for the **high frequency** component of the grid current.

**512.** Now, taking the curve given in Fig. 278, it is clear that to get the maximum **change** of anode current, the grid potential should be varied through 160 volts so as to change the valve current between zero and the saturation value.

This change, however, can be obtained in several ways (Fig. 278).

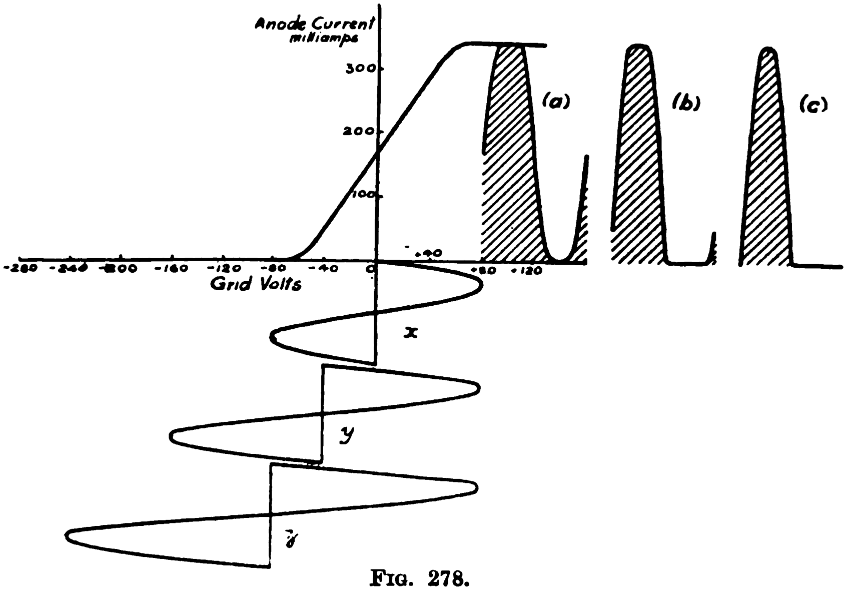


Fig. 278.

If we keep the steady potential of the grid at zero, and vary it ± 80 volts, we shall get a resulting variation of anode current as at (*a*).

If we keep the steady grid potential at — 40 volts, and vary it ± 120 volts (curve *y*) we shall get a current curve as at (*b*).

Similarly, by keeping the steady grid potential at — 80 volts, and varying it ± 160 volts (curve *z*) we get a current curve as at (*c*).

Now curve (*c*) has a great advantage over curve (*a*) :—

> In curve (*c*) current is flowing through both the grid and anode paths in the valve during each cycle for a much shorter time than in curve (*a*)—as indicated by the shaded areas—so that the watts wasted in the valve and the heating of the anode are decreased.

Hence this device of making the grid rectify a charge on itself and maintain a certain steady potential negative to the filament possesses the advantage of decreasing the energy wasted in the valve, so making for great efficiency of generation of aerial oscillations.

As the time during which current is rising and falling through the valve lasts for only a small fraction of the cycle of E.M.F. applied to the grid, the positive and negative impulses applied to the aerial will not be applied continuously during each cycle of the aerial oscillation, but will consist of **sudden** "**shocks**" of a very high voltage applied just at the correct moments for maintaining the aerial oscillation. These shocks occur at the moments when the oscillatory potential applied by the aerial oscillation to the grid render it sufficiently positive to allow current to rise and fall through the valve.

**513.** This system of energising the aerial is liable to give rise to the generation of harmonics. It may be taken as a general rule that if an oscillatory circuit is energised by a **sinusoidal** E.M.F., then a current which follows the true sine curve form will be generated in the circuit, *i.e.*, the circuit will oscillate at the frequency to which it is tuned. If, however, the excitation takes the form of a series of shocks, even though timed exactly to the frequency of the circuit, then in addition to the fundamental frequency, harmonics, *i.e.*, currents at frequencies which are multiples of the fundamental—will be generated.

Hence the use of a grid leak, though greatly increasing the **efficiency** of generation of oscillations, leads also to the generation of harmonics, which are especially noticeable in the case of high-power stations.

NOTE.—It is usual to fit the grid leak and condenser between the tuned circuit and the grid itself, so that the tuned circuit is not subjected to the high negative potentials brought about by the presence of the leak.

**514. The Coupled Circuit.**—Certain conditions give rise to peculiar difficulties in designing valve transmitting circuits.

In the generation of very short wave-lengths, a difficulty arises that any change in the aerial capacity—due to the aerial swaying in the wind, the movement of a turret near the aerial, &c. —will seriously affect the LC value and frequency of the transmitted wave.

This will result in the note heard by the receiving station rising and falling, and will render reception difficult.

A second difficulty sometimes met with is that the insulation of the aerial may fall to a very low value—as might occur in a submarine with the aerial "washing over," or in a big ship during heavy rain—and the load thus unexpectedly thrown on the valve may exceed its reserve of power, stop the aerial oscillations and prevent their starting again.

In both these cases it is preferable to use some form of intermediate circuit between valve and aerial instead of connecting the valve directly to the aerial circuit.

Fig. 279 illustrates the use of a closed primary circuit coupled inductively to the aerial.

The primary consists of a tuning condenser, a tuning inductance, and a coupling coil, which transfers the energy to the aerial.

It is found that, provided the coupling to the aerial is kept sufficiently loose, the length of the wave radiated depends **solely on the tuning of the primary,** and alterations in the capacity of the aerial make no difference to the transmitted wave-lengths, but only alter its **amplitude,** when the aerial circuit gets slightly out of resonance with the primary.

As regards the second difficulty of intermittent heavy aerial damping, a closed primary circuit affords the valve an efficient circuit on which to oscillate, whether the aerial is oscillating or not.

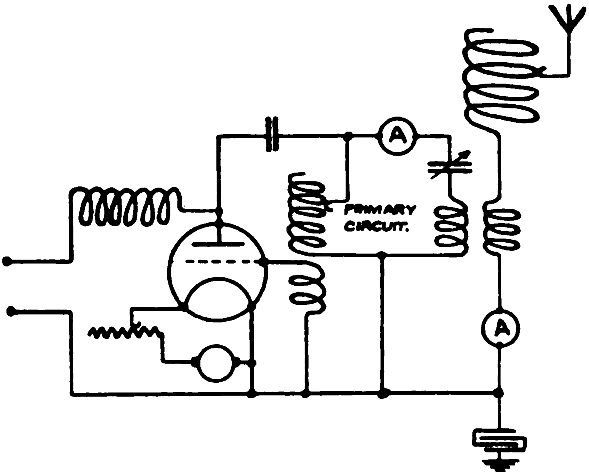
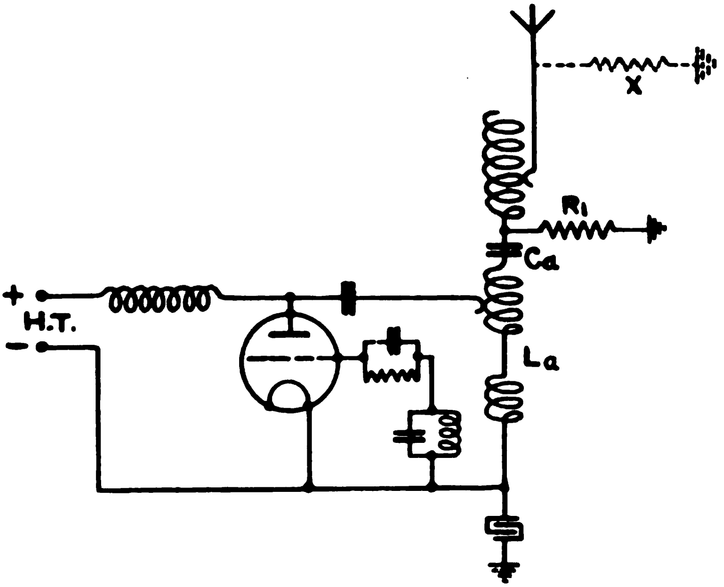


FIG. 279.

The primary circuit will always be trying to force current into the aerial, and will tend to dry off the moisture from the aerial insulators when given an opportunity.

**515. Drying-out Circuit.**—This is another form of circuit which is useful for dealing with intermittent heavy aerial damping.



*Drying-out Circuit.*

FIG. 280.

It consists of a series acceptor circuit ($L_2C_2$) introduced into the aerial circuit, and a connection to earth through a resistance ($R_1$) from the junction of these two circuits.

The introduction of the acceptor circuit $L_2C_2$ has provided a circuit which will oscillate even if the aerial circuit is earthed at the deck insulator.

Now, the aerial circuit is resistance-coupled to this circuit by reason of the P.D. across the resistance $R_1$.

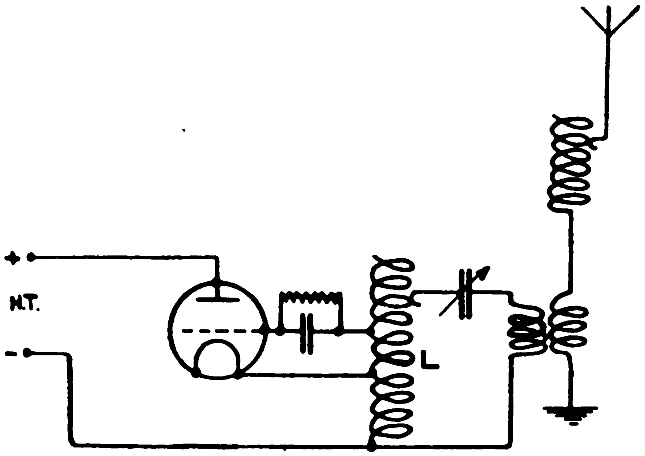
If the deck insulator is earthed by salt water over its surface as indicated at x, the high frequency P.D. across it will cause a leakage current to flow through this moisture, tending to dry off the insulator. At the same time, provided the aerial and acceptor circuits are in resonance, oscillations will be forced on the aerial circuit.

As the deck insulator is a point of high potential in the aerial circuit, the moisture is rapidly dried off once the aerial oscillations are set up.

This loss by leakage is equivalent to a damping loss $R_2$ introduced into the aerial.

The circuit is similar to that described in Chapter VIII., p. 279. As pointed out there, the joint resistance of $R_1$ and $R_2$ is equal to $\frac{R_1 \times R_2}{R_1 + R_2}$, and can never be greater than $R_1$, however great the aerial damping.

**516. Direct Coupled Circuit.**—A somewhat unusual form of circuit is illustrated in Fig. 281. In this circuit the grid and filament are connected **directly** to a portion of the inductance L of the oscillatory circuit, and the variations in valve current consequent upon variations in grid-filament potential are made to pass from the filament through the lower portion of the inductance L and so back to the high voltage supply source.



*Direct-Coupled Circuit.*

FIG. 281.

This system is convenient for low-power circuits, having a minimum of adjustments, but has two disadvantages :—

(*a*) The inductance L is carrying a direct current at very high voltage, and is therefore dangerous to touch.

(*b*) The filament heating system must be carefully insulated from earth.

**517. The High Potential Supply.**—Provided that the anode of a transmitting valve is sufficiently large to dissipate the necessary power, the effectiveness of a valve is greater the higher the potential of its supply current.

In other words, for a given electron emission of the filament the power dealt with by the valve will be greater the higher the potential of its anode supply.

A high potential supply may be provided by :—

(*a*) A motor generator giving a direct current output at very high voltage.

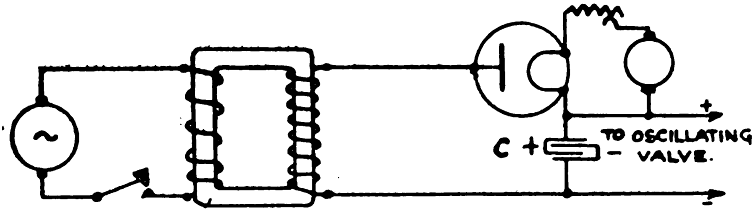
(*b*) A motor alternator and transformer with "rectifying valves."

The first method is in some ways the simplest, but there is a difficulty in securing suitable motor-generator sets giving a voltage sufficiently high, and in some respects the rectifying valve supply possesses distinct advantages over a D.C. machine, as will be mentioned subsequently.

**518. The Rectifier System.**—What is required for the oscillating valve is a high voltage **direct** supply.

Now, in most W/T offices we already have available the transformer of the spark transmitting circuit, which provides a high voltage **alternating** supply.

All that is necessary is to rectify this alternating current into direct current.



*Single-Phase Rectified A.C. Circuit.*

FIG. 282.

**Simplest Rectifying Circuit.**—Fig. 282 illustrates the simplest type of rectifier circuit.

It comprises :—

An alternator, transformer, and signalling key.

A rectifying valve : this merely consists of an ordinary transmitting valve with the grid omitted (or "diode").

A motor generator and rheostat for supplying and controlling the current for heating the filament of the rectifying valve.

A cushioning condenser, C, of large capacity.

Supply leads to the anode and filament of the oscillating valve.

**Action.**—When the key in the low tension A.C. circuit is pressed, an alternating voltage of high value will be applied to the anode of the rectifying valve.

The rectifying valve will only pass current through itself when its anode is positive to its filament.

So that during each **positive** half-cycle current will flow through the valve into the condenser C, charging it up.

During each **negative** half-cycle, the anode of the valve is negative to its filament, and no current flows in the reverse direction.

Hence the condenser receives a charge during each positive half-cycle, and a steady voltage is established across its plates, depending on the current taken from it by the oscillating circuit, and the current supplied to it by the valve.

This action is illustrated in Fig. 283.

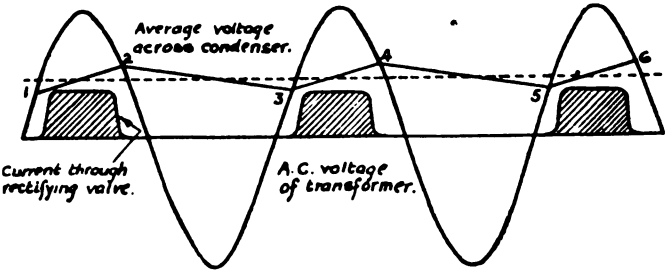

Average voltage across condenser.
1
2
3
4
5
6
Current through rectifying valve.
A.C. voltage of transformer.

FIG. 283.

The alternating voltage across the secondary of the transformer is shown (thin line curve), while the dotted line indicates the average voltage across the cushioning condenser.

Whenever the alternating voltage rises above that across the condenser—at moments 1, 3, 5—current starts flowing through the valve, as indicated by the thick curve, and quickly rises to the saturation value—hence the flat top of the curve.

The shaded areas under the thick line indicate charges of electricity introduced into the condenser.

The voltage across the condenser is not absolutely steady. Between moments 2 and 3 current is flowing out of the condenser to the oscillating circuit, but none is flowing in, so that the voltage across the condenser falls off.

Between moments 1 and 2, current is flowing into the condenser from the rectifying valve faster than it is flowing out to the oscillating circuit, so that the condenser voltage rises.

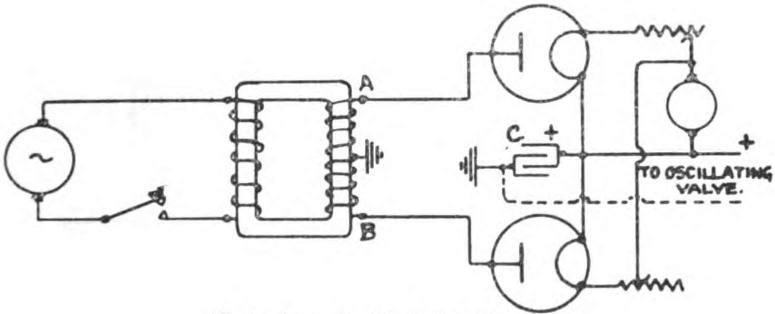
Hence the rectified supply is not absolutely steady, but has a slight rise and fall or "**ripple**" at the frequency of the A.C. supply.

This is not undesirable, but gives a characteristic note to C.W. transmitters using a rectified A.C. supply.

If it were not for the cushioning condenser this ripple would be very much more pronounced, and would make the transmitted signal readable without the use of a heterodyne circuit.

**519. Two-Phase Rectifier Unit.**—In Fig. 282 one valve is used, with the full voltage of the transformer applied across it.

In Fig. 284, a "two-phase" system is shown, in which a rectifying valve is joined to each high tension terminal of the transformer.



*Two-phase Rectified A.C. Circuit.*

Fig. 284.

Their filaments are fed in parallel from a motor-generator through separate rheostats, and the cushioning condenser *c* is joined between the common filament connection and the central earthed point of the transformer.

**Action.**—The valves are joined in between the high tension terminals of the transformer and its earthed centre point. Therefore, as the voltage of each high tension terminal rises and falls above and below earth potential, current flows through the two valves alternately into the cushioning condenser.

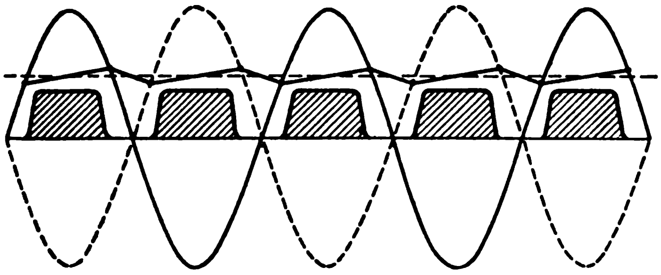


Fig. 285.

This results in a charge being put into the condenser at every half-cycle of the A.C. supply, as illustrated in Fig. 285, and in consequence the ripple on the steady condenser voltage is much less pronounced, and at a higher frequency.

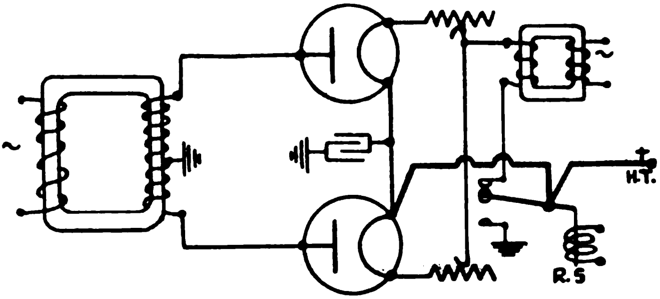
This is the arrangement generally used in practice.

**520. Heating of Rectifier Filaments.**—A special difficulty arises with the rectifier system of D.C. supply, that the filaments of the two valves and the source of current for heating the filaments are at a very high potential above earth, and, consequently, have to be very carefully insulated.

If a battery is used it may be placed in a tray mounted on porcelain pillars.

If a motor generator is used, the generator must be mounted on insulation, and an insulated connection made between its shaft and that of the motor driving it.

A third method is to heat the filament by alternating current, as indicated in Fig. 286.



*Filament—Heating Transformer and Rectifier Switch* (*R.S.*).

Fig. 286.

Here the filaments of the rectifying valves are shown as being heated by A.C. taken from the secondary of a small transformer which steps the voltage down to a suitable value.

It is convenient to provide a separate rheostat or inductance choke control for each filament, in case the characteristics of the two valves are not exactly the same.

The advantage of this method is that it is a very easy matter to insulate the secondary windings of the transformer used.

The alternations of the heating current make no difference to the rectified A.C. supply.

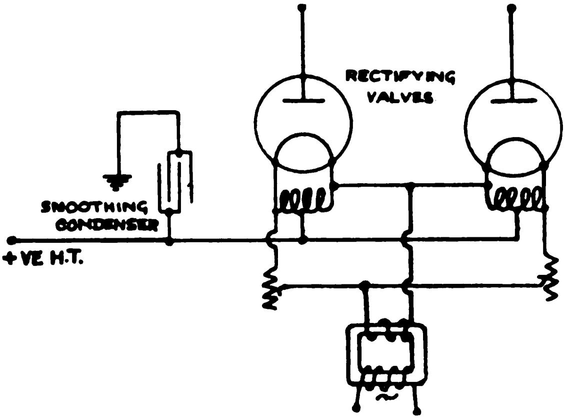
An electrically operated switch (R.S.) is used for completing the circuit to the filaments, and for discharging the rectifier condenser to earth when transmission has ceased.

**521. Use of an Equaliser Coil.**—In cases where large powers are being dealt with, the arrangement shown in Fig. 286 of tapping off the H.T. rectified supply from **one side** of the two rectifier valve filaments, is unsuitable.

It must be remembered that the filament is generally arranged as a loop, and consequently if the arrangement shown in Fig. 286 is used, one side of the loop would be carrying all the rectified current, while the other half would carry none.

This would mean that the filament would have an unduly short life.

It is preferable then to arrange the rectifier filament circuits as in Fig. 287, where we have an "**equaliser coil**" joined across the two filaments, and the high tension lead to the oscillating valve connected to the mid-point of each coil.



*Illustrating use of Equaliser Coils.*
FIG. 287.

The equaliser coil has a high inductance, and consequently takes very little of the filament heating current.

The flow of H.T. rectified current, however, is in opposite directions in the two halves of the coil, which is consequently non-inductive to it.

Thus paths of equal conductivity are provided for the rectified current down both sides of the filament simultaneously, so equalising the current distribution in the two halves of the filament loop.

**522. Variation of Rectifier Voltage.**—It should be observed that the voltage across the rectifier condenser depends on the following factors :—

(*a*) The alternating voltage.
(*b*) The heating current of the rectifier filaments.
(*c*) The current taken by the oscillating circuit.

An increase of (*a*) or (*b*) will increase the voltage applied to the valve, while an increase of (*c*) will decrease it, observing that the greater the current taken by the oscillator, the greater the quantity that must be fed into the rectifier condenser per cycle from the rectifier. This quantity depends upon the saturation current and the time for which the alternating voltage exceeds the condenser voltage. If the saturation current is fixed, then the time it flows must increase with an increased quantity to supply. This can only happen by a fall in the condenser voltage.

Four points should be noted in this connection :—

(*a*) As the transmitting valve is always most effective when the voltage applied to it is highest, the **anode tapping point** should be varied until the current flowing to the anode of the oscillating valve is **least,** for then the rectifier voltage will be greatest.

(*b*) If the anode of the transmitting valve gets hot during a long spell of signalling, this indicates that the rectifier voltage is too high.

The alternating voltage should then be lowered, or the filament current of the transmitting valve may be **raised,** as this will result in more current being taken from the rectifier condenser, and the voltage across the latter will fall off. If, however, the filament voltage is already at its emission value, it is undesirable to raise it higher, as the valve may soften.

(*c*) If the oscillating valve softens in action, the current taken by it rises, and would tend to burn the valve out, but then the rectifier voltage **falls,** and the valve is saved.

(*d*) If the rectifier anode overheats, its temperature may be reduced by **raising** the rectifier filament current. This will result in an increase of rectifier condenser voltage, and consequently in (i) a reduction in the **time** during which rectified current is flowing through the rectifying valve during each positive half cycle, and (ii) a reduction of potential difference between anode and filament.

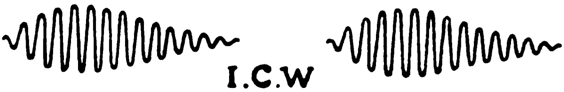
These two reductions outweigh the increase of emission current and the resulting power dissipation at the anode is reduced, so reducing its temperature.

**523. Interrupted C.W.**—It is frequently necessary for a ship to communicate with another ship or station which has not got a heterodyne receiver.

In this case an ordinary continuous wave is of no use, but the transmitted wave must be made to vary in amplitude at **audible frequency.**

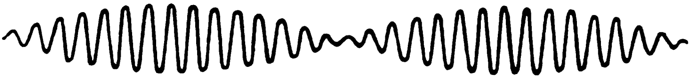
Of course, a spark transmitting installation can be used for this purpose, but a great saving in space and cost can be effected if the C.W. transmitting installation can be used to transmit also a wave which is varying at **audible frequency.**

The term " Interrupted Continuous Waves " (abbreviated to " I.C.W.") is used generally to denote continuous waves in which the amplitude or frequency is varied in a periodic manner at an audible frequency (Fig. 288 (*a*) ).



**I.C.W**

**(*a*)**



***Tonic Train.***

(*b*)

FIG. 288.

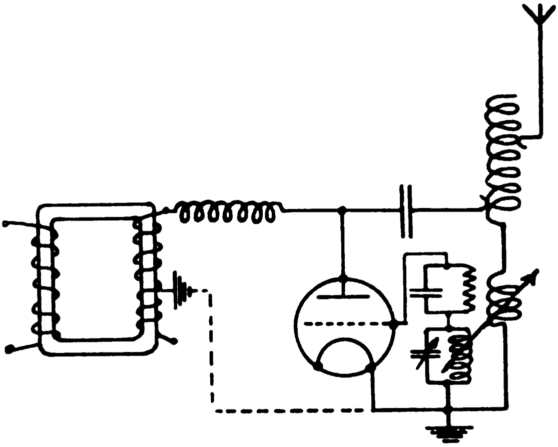
The term "Tonic Trains" is applied to audible frequency modulation when the variation in amplitude is approximately **sinusoidal** (Fig. 288 (*b*) ).

I.C.W. may be produced by any of the following methods :—

(*a*) We know that when a steady voltage is applied to the anode of a transmitting valve, a **uniform** high frequency oscillation of **constant amplitude** is generated in the aerial.

If then an **alternating voltage** is applied to the transmitting valve, a high frequency oscillation will be generated whose amplitude will vary at alternating frequency.

Fig. 289 illustrates a typical transmitting valve and oscillating circuit similar to that shown in Fig. 277, but half the secondary of a transformer is joined directly across between its anode and filament.



*Single-Pulse I.C.W. Circuit.*

FIG. 289.

Fig. 290 illustrates what occurs. Whenever the anode is positive to the filament an oscillation is set up in the aerial, which rises quickly from zero to a maximum, and dies away again as the anode voltage falls.

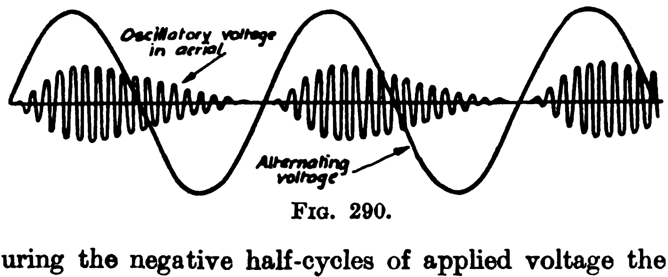


FIG. 290.

During the negative half-cycles of applied voltage the valve ceases to maintain the aerial oscillation, which consequently dies away.

We thus get a succession of " damped wave trains "—one for each cycle of the A.C. supply—and these, when applied to the detector of the receiving ship will give rise to a note in the telephones without requiring a heterodyne.

The note given is a pure one, whose pitch corresponds with that of the frequency of the alternating supply.

The only alteration necessary to the rectifier circuit shown in Fig. 284, when it is required to connect up for transmitting tonic trains, is to disconnect the positive lead to the valve from the right-hand plate of the rectifier condenser, and join it to either of the points marked A or B.

As the rectifying valves are no longer required to function, current should be switched off from their filaments.

(*b*) A second method of producing I.C.W. is to utilise the rectifying valves but to disconnect the rectifier condenser. Then the ripples on the rectified supply indicated in Fig. 285 will become very marked, and the action occurring will be very much as illustrated in Fig. 291.

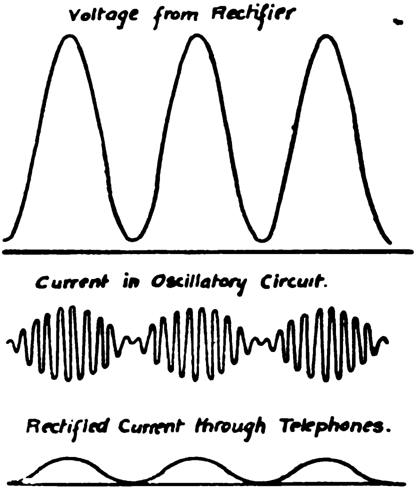

Voltage from Rectifier
Current in Oscillatory Circuit.
Rectified Current through Telephones.

FIG. 291.

The voltage from the rectifier will never fall quite to zero, on account of the inductance of the anode choke coil, which will tend to keep the current flowing during the very short intervals between the current impulses from one or other of the two rectifying valves.

It should be noticed that as both rectifying valves are functioning, the variations in the supply voltage will be at twice the frequency of the A.C. supply, and so this method gives a note double the frequency of that given by method (*a*).

For this reason the wave emitted is termed a "double pulse."

(*c*) A third method of producing I.C.W. is to interrupt the oscillations by making and breaking the grid lead of the oscillating circuit at audible frequency.

This can be effected by inserting a buzzer wheel in the grid circuit.

The effect will then be that when the buzzer brush is bearing on a conducting segment an oscillation will set up in the aerial, but when it bears on an insulated segment the grid will be left insulated and will accumulate such a negative charge that the aerial oscillation will be stopped.

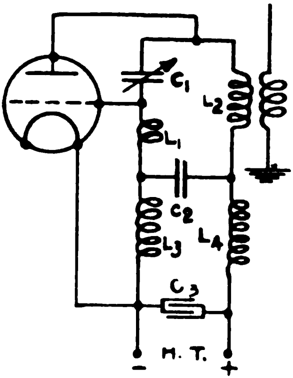
The result will be a tonic train of a frequency depending on the speed of revolution of the buzzer wheel.

This latter method is suitable for use with an A.C. source of supply whose frequency is too low to give a good note.

I.C.W. produced in this manner is sometimes termed "**chopped C.W.**"

(*d*) A fourth method involves the use of combined high and low frequency circuits, as in Fig. 292.

This circuit comprises (*a*) the high-frequency circuit $L_1$, $L_2$, $C_1$, and (*b*) the low frequency circuit $L_3$, $C_2$, $L_4$, $C_3$.



*I.C.W. Circuit modulated D.C. supply*

FIG. 292.

Consider the high frequency circuit first. The two inductances $L_1$, $L_2$ are in series, and are therefore added together. The small condenser $C_1$ is in series with the large condenser $C_2$ and will consequently be the controlling factor. Thus the tuning of the high frequency circuit will depend on the values of the inductances $L_1$ and $L_2$ and of the condenser $C_1$.

The variations in voltage across the inductance $L_1$, being applied between grid and filament, will vary the valve current at radio frequency.

The presence of the circuit $L_3$, $C_2$, $L_4$, $C_3$, which is tuned to some audio-frequency such as 1,000 cycles per second, will cause an audio-frequency variation in valve current.

The combination of these two will result in the emission from the aerial of a radio-frequency wave which is modulated sinusoidally at audio-frequency.

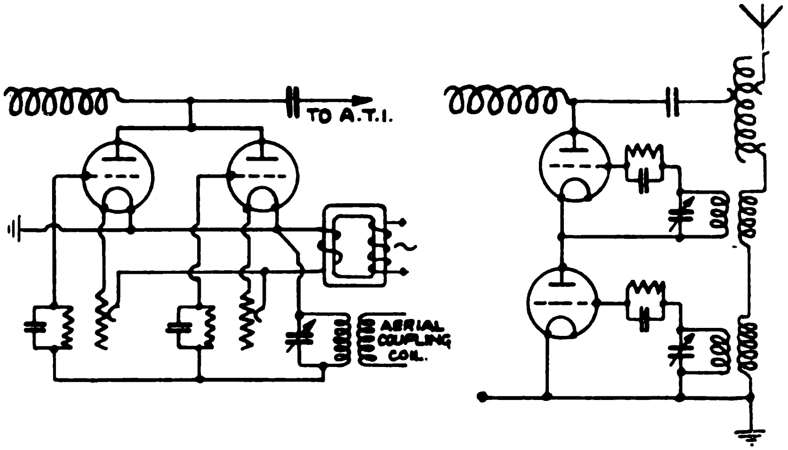
All these four methods can be used to transmit signals which are directly readable on a crystal or valve detector without the use of a heterodyne circuit.

**524. Series and Parallel Arrangement of Valves.**—For high power valve transmission it is usual

(*a*) to have a large number of valves grouped together, and

(*b*) to work at as high an anode voltage as possible, without puncturing the valve or setting up a blue glow (para. **451**).

An arrangement of **valves in parallel** is illustrated in Fig. 293 (*a*).



*Transmitting Valves in Parallel.* (*a*)

*Transmitting Valves in Series.* (*b*)

Fig. 293.

It will be noticed that the anodes are joined in parallel, and the whole arrangement may therefore be regarded as one valve of twice the anode rating of the individual valves.

The grids have each their own insulating condenser and leak, and then are connected in parallel to the grid coupling circuit. The filaments are joined in parallel to a filament-heating transformer, but a separate rheostat is provided for each.

Remembering our definition of the ideal anode tapping point (para. **510**), it will be seen that since we have in effect a valve of twice the anode rating of the individual valves, the anode tapping point can be lowered until the aerial current reaches twice the value possible with one valve, without overheating the anodes.

Therefore to get maximum aerial current, the anode tapping point becomes very low, and in actual practice this adjustment is very critical.

A further difficulty with regard to the use of large aerial powers, at the limited safe anode voltage for the valves when in parallel, is the large anode current necessary.

This necessitates the design of rectifying valves giving large emission currents, or the use of several rectifying valves in parallel, when the H.T. power supply is rectified A.C.

**Valves in Series.**—Fig. 293 (*b*) shows an arrangement in which two valves are connected **in series** between the H.T. supply and earth.

The grids have separate grid leaks and oscillatory circuits, coupled to the aerial circuit.

With proper adjustment of each grid circuit the oscillatory voltages across each valve can be adjusted to be equal and to be the maximum which either valve can safely carry.

The supply power to the circuit is then twice that for a single valve operated at the same anode current and at its maximum safe anode potential, which is half the value of the maximum safe anode potential for two valves in series.

The arrangement has two advantages over the parallel circuit :—

(*a*) The higher anode voltage admits of a higher and less critical anode tapping for a given anode current.

(*b*) The rectifying valves can be designed to have a smaller emission.

It should, however, be noted that the potential stress on the rectifiers is more severe with the series circuits, as much higher voltages must be used to get the full power output from the oscillating valves.

For very high power circuits, groupings of valves in a series-parallel arrangement may be found desirable.

**525.—Valve Transmitting Circuit Complete.**—Fig. 294 illustrates a valve transmitting circuit complete with rectifier unit. The items shown are :—

(1) A magnetic key, for interrupting the A.C. supply.

(2) The step-up transformer.

(3) (3) The rectifying valves.

(4) (4) The equaliser coils.

(5) The rectifier switch (electrically operated) for discharging the rectifier condenser, when transmission is finished.

(6) The transformer for the rectifier filaments.

(7) (7) The rheostats for control of current to the rectifier filaments.

(8) The rectifier condenser, of large capacity.

(9) The anode choke coil.

(10) (10) The oscillating valves.

(11) (11) The grid insulating condensers and leaks.

(12) The transformer for supplying current to the filaments of the oscillating valves.

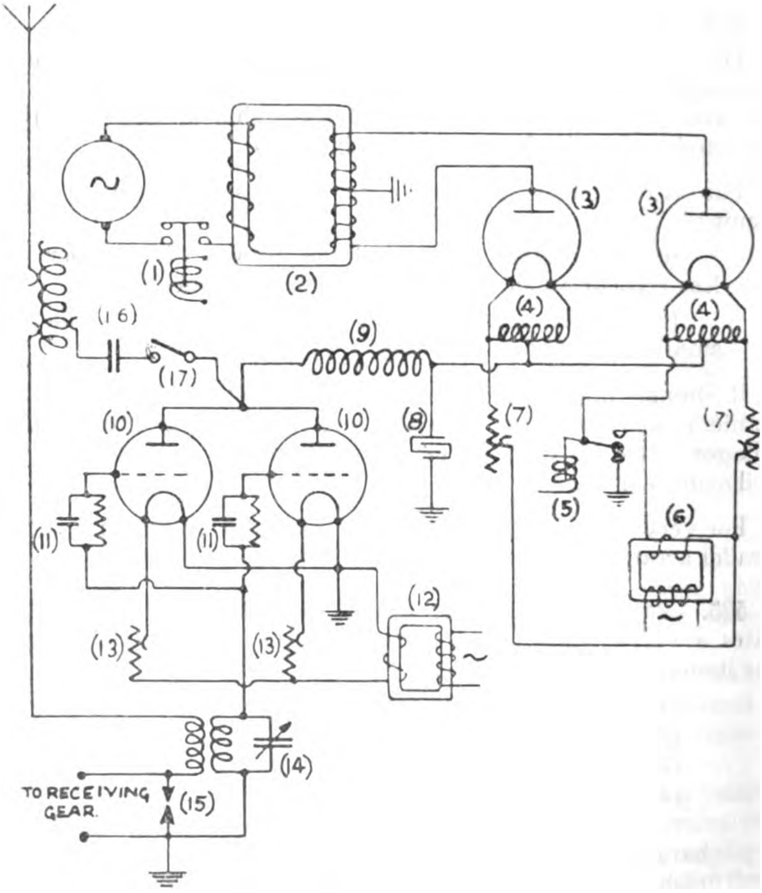
(13) (13) The oscillating valve rheostats.

(14) The grid coupling circuit.

(15) The send-receive contact, across which the receiving gear is joined.

(16) The anode blocking condenser.

(17) The anode key, for breaking the lead from aerial to the anodes when the transmitting key is not pressed. If it were not for this break, there would be a path to earth for received signals through the aerial coil, anode blocking condenser, anode choke coil and rectifier condenser.



*Valve Transmitting Circuit Complete.*

FIG. 294.

## CHAPTER XIV.

## RADIO-TELEPHONY.

**526.** By "Radio-Telephony" (R/T) is meant direct communication by speech by wireless methods, whereas "Wireless Telegraphy" indicates the use of the Morse Code.

The relative merits of R/T as compared to W/T, so far as the Service is concerned, are as follows:—

**Advantages.**

(*a*) Communication is more rapid in the case of short messages.

(*b*) Knowledge of Morse is not required.

(*c*) Principals—*e.g.*, Admirals and Captains, Control Officers, &c.—are able to converse directly with one another.

**Disadvantages.**

(*a*) Coded messages are difficult to pass, owing to risk of phonetic errors, and plain language involves the risk of interception.

(*b*) R/T is slower than W/T in cases where the message must be written down.

(*c*) The interference caused by R/T is worse than that of W/T (C.W. or I.C.W.) signals.

**527. Sound.**—We must first consider the nature of **Speech,** and in this connection also what is meant by "**Sound**"—musical and otherwise.

An understanding of the nature of Sound is of great help through the study of both W/T and R/T.

Sound may be defined as an alternate compression and rarefaction of any medium caused by a vibrating body, and in order that the sound may be appreciated by the human ear the frequency of vibration, and hence of the alternate compression and rarefaction of the medium, must lie between certain fairly well-defined limits.

The most common medium for the transmission of sound is the atmosphere. Under normal conditions the vibrations of a sound source will cause the bands of alternate compression and rarefaction—or "sound waves," as they are termed—to be propagated radially outwards, thanks to the elasticity of the air.

The velocity of sound in air is 1,132 feet per second in air at a temperature of 70° Fahr. Sound waves of all frequencies travel in the open air, under similar conditions, with the same velocity.

**528. Noise and Tone.**—The ear divides sounds roughly into two classes: **noises,** which are disagreeable or irritating, and

**tones,** which are received with pleasure or indifference. Noise and tone are merely terms of contrast, in extreme cases clearly distinct, but in other instances blending; the difference between noise and tone is one of degree.

**Words** are multiple tones of great complexity, blended and flowing, mixed with essential noises.

If with the vowel tone **a** (mat) we combine a final noise represented by **t,** the word **a+t** is produced; if to this simple combination we add various initial noises, several words are formed, as: b + at, c + at, &c.

**Tones** are sounds having such continuity and definiteness that their characteristics may be appreciated by the ear, thus rendering them useful for musical purposes; these characteristics are **pitch** or **frequency, loudness** or **intensity,** and **tone quality.**

**529. Pitch or Frequency.**—A sound is said to have a high pitch when its frequency is high; *i.e.*, pitch and frequency are practically synonymous.

As stated in the first chapter, the piano has a range of pitch from 27·2 to 4138·4.

The middle octave of the piano has the following pitches (an **octave** being a range of 8 pitches, the top one of which is twice the frequency of the bottom one):—

**Octave above Middle C.**
**(International Scale.)**

$C_3$ = 258·65 cycles per second.
$D_3$ = 290·33 ,, ,, ,,
$E_3$ = 325·88 ,, ,, ,,
$F_3$ = 345·26 ,, ,, ,,
$G_3$ = 387·54 ,, ,, ,,
$A_3$ = 435·00 ,, ,, ,,
$B_3$ = 488·27 ,, ,, ,,
$C_4$ = 517·31 ,, ,, ,,

The term **loudness** explains itself; it is a comparative statement of the strength of the sensation received through the ear, and depends on the **amplitude** of the vibration.

**530.** The third property of tone is much the most complicated: it is that characteristic of sounds, produced by some particular instrument or voice, by which they are distinguished from sounds of the same loudness and pitch, produced by other instruments or voices.

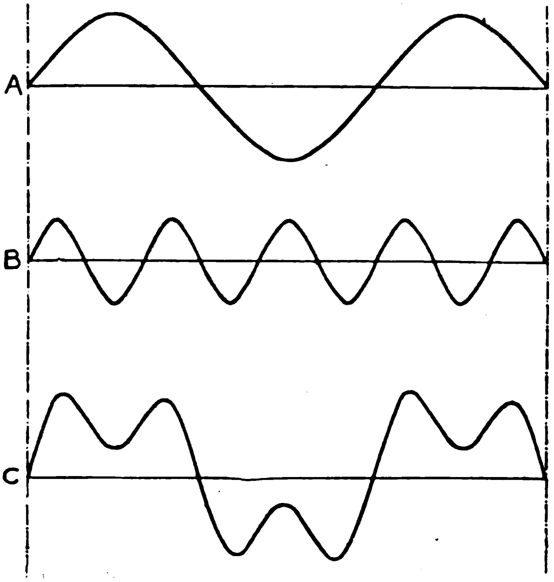
This characteristic may be called **tone quality.**

The wave produced by a tuning fork is a simple sine curve.

Let us suppose a tuning fork is sounded and is producing the sine wave A, in Fig. 295.

Let us sound a second fork whose frequency is three times that of the first, as in curve B.

The two waves will blend together, and will give to the ear the complicated curve C, which is found by adding curves A and B together algebraically.



Wave form resulting from the composition of two simple waves.

FIG. 295.

The combined sound will have a different tone quality to that given by either fork alone.

This argument may be extended indefinitely to include any number of simple tones of any selected frequencies, amplitudes, and phases. There are therefore peculiarities in the motion of a single particle of air which differ for a single tone and for a combination of tones.

Ohm's Law of Acoustics states: "All musical tones are "periodic; the human ear perceives pendular (sine curve) "vibrations alone as simple tones; all varieties of tone quality are "due to particular combinations of a larger or smaller number "of simple tones; every motion of the air which corresponds to "a complex musical tone or to a composite mass of musical "tones is capable of being analysed into a sum of simple "pendular vibrations, and to each simple vibration corresponds "a simple tone which the ear may hear."

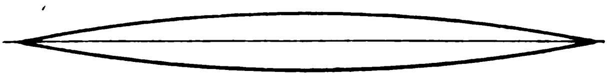
From this principle it follows that nearly all the sounds which we study are composites.

The separate component tones are called partial tones, or simply partials; the partial having the lowest frequency is the fundamental, while the others are overtones or upper partials.

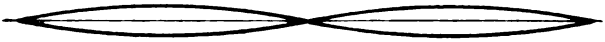
If the overtones have frequencies which are exact multiples of that of the fundamental they are often called harmonics.

Fig. 296 shows a string vibrating at its fundamental frequency and also at its second, third and fifth harmonics.

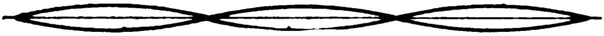
FUNDAMENTAL.



SECOND HARMONIC.



THIRD HARMONIC



FIFTH HARMONIC.

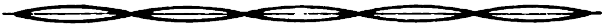
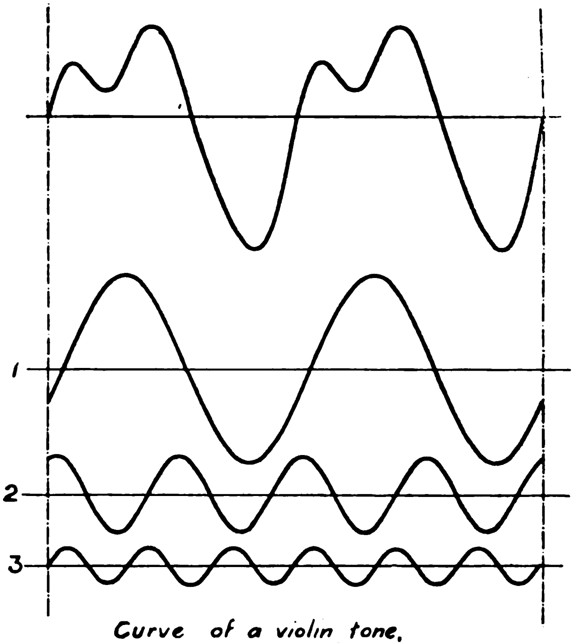


FIG. 296.

If the frequency of the single loop is 100, the two loops would have a frequency of 200, the three loops a frequency of 300, and the five loops a frequency of 500.



Curve of a violin tone,
& its three harmonic components

FIG. 297.

The top curve in Fig. 297 shows a sound wave from the tone $B_4 = 995$, played on the E string of a violin. This curve may be analysed into three simple curves, 1, 2, and 3, which, added together algebraically, make up the upper curve.

It is the combination of these three curves that gives the characteristic violin tone quality to the note.

**531. Speech.**—In the back of the throat of the speaker a sort of membrane known as the " vocal chords " is set into more or less continuous vibration by a breath. The quality of the resulting sound is modified in at least two ways: by altering the shape of the mouth with the tongue or otherwise and thus causing a degree of selective resonance, and by actually starting and stopping the stream of sound, as is done with the harsher consonants, *e.g.*, the letter " d."

The extreme complexity of the resultant sound vibration of the air is illustrated in the curve of Fig. 298.

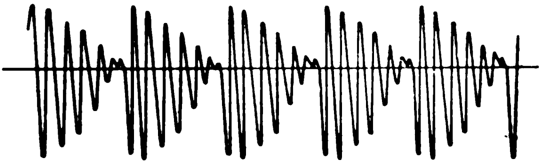


FIG. 298.

This is a record of the current in a telephone line (and therefore approximately of the sound in a receiver) corresponding to the sustained vowel sound " ah " (as in " bah "), a clear speaking man's voice being used for the test. The total time of the record is slightly over one-twentieth of a second. The fundamental vibration was of approximate frequency of 800 cycles per second, and the chief modification thereof occurs with a frequency of 120 cycles per second.

The great complexity of speech, even for the comparative crudity of radio-telephony, becomes obvious.

In W/T as nearly as possible complete and abrupt starting of energy flow is required and this at no very rapid rate.

In R/T, on the other hand, the outgoing flow of energy must be moulded and modulated with close approximation to the excessively complicated wave form of the speech vibrations.

The difference in degree is not far from that between ruling a dot-and-dash line and making a dry-point etching of an autumn landscape.

**532. The Microphone.**—The modulation control in R/T is effected by means of a microphone. Various designs are in use, but they are mostly based on the simple type used in land line telephony.

The simplest possible form is illustrated in Fig. 299, and consists merely of a carbon pencil resting between two carbon blocks attached to a sounding board, the battery and receiver being joined up as shown.

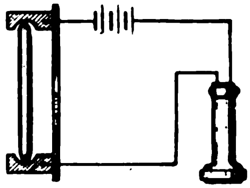


Fig. 299.

Action.—So long as the sounding board remains stationary the current in the circuit remains steady, but as soon as the sounding board is thrown into a state of vibration the contacts between the carbon rod and the blocks are varied, thus producing what are called "phenomena of loose contact," and causing alterations in the resistance of the transmitter. The corresponding alterations ot current in the total circuit act on the receiver, causing the telephone diaphragm to be moved by the variations in current through the telephone windings.

It is, in fact, a relay actuated by the voice, and is exceedingly sensitive, the slightest displacement of the carbon being audible in the receiver. Other systems of loose contacts will act as transmitters, but carbon is undoubtedly the most efficient, as it is practically infusible, inoxidisable, and a poor conductor.

The efficiency of the varying contact is very greatly improved by employing carbon dust in contact with a thin disc, usually made of carbon also.

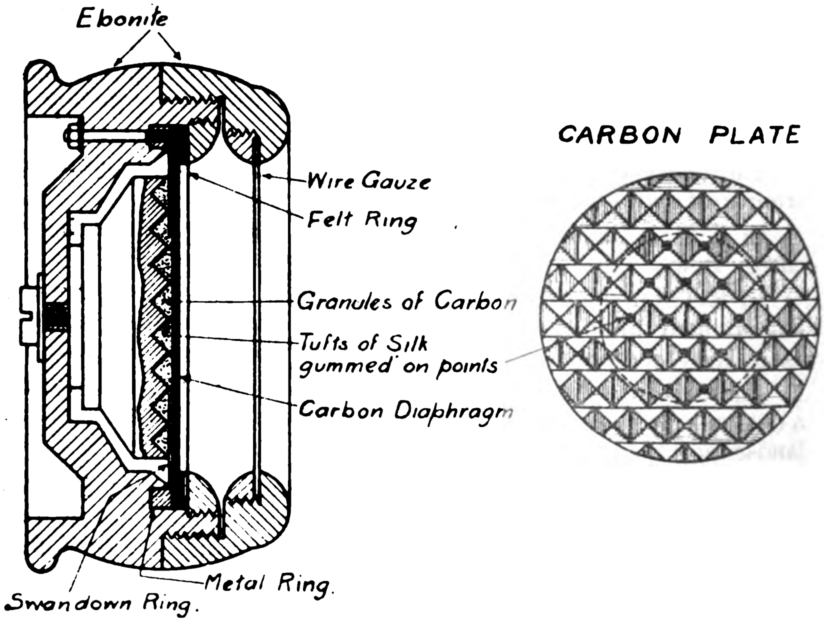


Fig. 300.

In a very common type of microphone, a carbon diaphragm is employed, being divided into a number of pyramid-shaped cones, on the points of which are fixed small tufts of silk; these damp the diaphragm vibrations and help to prevent "packing" by keeping the carbon granules in place; the construction of this transmitter will be understood from Fig. 300.

**533. Line Telephony.**—We will now consider the methods used in line telephony, which has many problems in common with radio telephony.

The simplest possible circuit is as illustrated in Fig. 301.

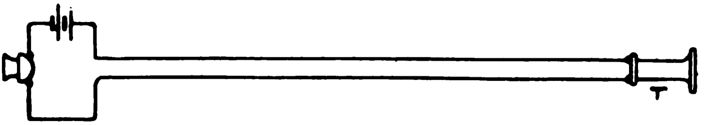


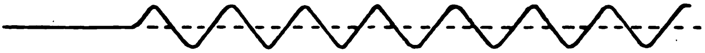
FIG. 301.

When no speech is occurring, a steady current will flow through the microphone, along the line, and through the telephone T.

We may term this current the **carrier current.**

Now when the microphone is spoken into, this current will be varied in amplitude, or **modulated.**

Suppose, for example, a tuning fork, tuned to the middle C, is sounded near the microphone, then a pure sine wave of frequency 256 cycles per second will be impressed on the carrier current as in Fig. 302.



*Telephone Current, with Sinusoidal Modulation.*

FIG. 302.

The current variations, passing through the telephone, will move the telephone diaphragm and the note of the tuning fork will be reproduced.

An improvement on the above circuit will be as shown in Fig. 303.

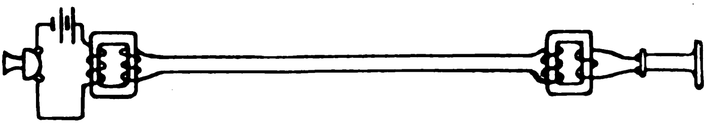


FIG. 303.

Here two transformers have been introduced. The carrier current is restricted to the transmitting apparatus. The variations in the carrier current—which we may term the **speech**

**current**—go through the transformer, pass along the line, and affect the receiver as before.

It should be noted that the carrier current is reintroduced at the receiving end, in effect, by the permanent magnetism of the telephone earpiece.

Actual speech, as previously stated, is composed of a great variety of frequencies, which for practical purposes may be taken as lying between 300 **and** 3,000 **cycles per second.** If we design our apparatus to transmit and reproduce this band of frequencies accurately, the quality of speech as heard in the telephone will be good.

For the transmission of music, frequencies between 100 and 5,000 are required.

**534. Radio Telephony.**—The same principle is involved in radio-telephony.

A continuous high frequency **carrier wave** is emitted, which if merely rectified, is turned into a steady direct current, and if heterodyned, gives a steady note in the telephones.

(It should be quite obvious that on no account must a heterodyne be used by the receiving station for the reception of R/T. Otherwise, a continuous note will be superimposed on the speech.)

By means of a microphone the voice of the speaker is made to vary the amplitude of this wave at the various audible frequencies which go to make up speech, and in consequence the telephone diaphragms in the receiving circuit are moved correspondingly, and reproduce the speech.

Let the rippling curve of Fig. 304 represent the sound vibrations corresponding to some spoken word.

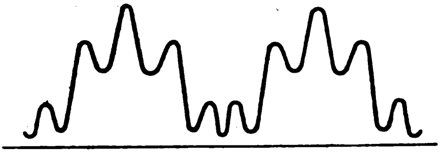


Fig. 304.

This represents the modulation we wish to impress on the carrier wave.

Fig. 305 illustrates the carrier wave rising and falling in amplitude in time with the speech modulation.

This is the shape of the wave as it is transmitted through the æther, to influence a receiving aerial.

If the wave is now applied to a suitable detector, the oscillatory current will be rectified into a current varying at audio-frequency, and the original curve of Fig. 304 will be reproduced, and will produce a sound in the telephones similar to the original speech.

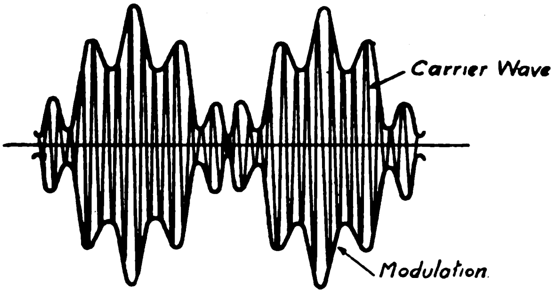


FIG. 305.

**536. Circuits used in Radio-Telephony.**—The various methods used of modulating the carrier wave may be classified as follows :—

(*a*) Modulating the resistance of the aerial.
(*b*) Modulating the grid voltage of the oscillating valve.
(*c*) Modulating the anode voltage of the oscillating valve.

**537. Modulation of Aerial Resistance.**—Fig. 306 illustrates a very simple and effective circuit.

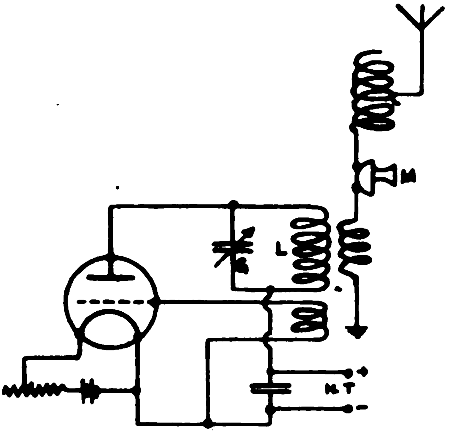


FIG. 306.

A valve and high potential battery are arranged to maintain a high frequency oscillation in the circuit LC, an inductive coupling to the grid being employed.

This circuit is inductively coupled to the aerial.

A microphone M is inserted directly in series with the aerial.

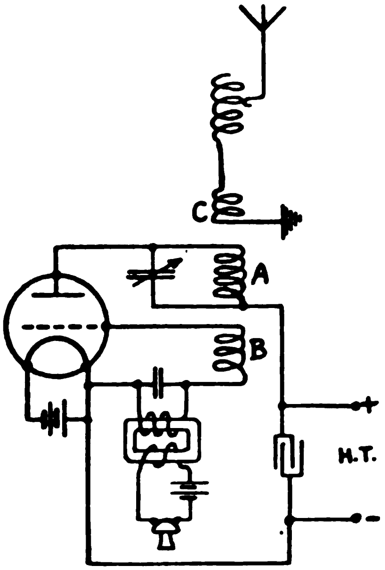
Action.—As soon as the filament current and high potential supply are switched on, the circuit LC is set in oscillation, and energises the aerial. A continuous carrier wave is consequently emitted.

When the microphone M is spoken into, its carbon granules are shaken up and its internal resistance varied in time with the low frequency sound waves of the voice.

This variation in the aerial resistance will modulate the **amplitude** of the carrier wave.

When the carrier wave is rectified by the receiving station the telephone diaphragms of the latter will be deflected in a similar manner, and will reproduce the speech.

**538. Modulating the Grid Voltage.**—Fig. 307 illustrates a method of connecting the microphone in the grid circuit of the oscillator.



*Grid Modulation Circuit.*

Fig. 307.

In this case if the microphone is idle the amplitude of the aerial current is constant, but if the microphone is excited by sound waves, speech currents will be produced in the microphone circuit which will produce audio-frequency E.M.F.s in the grid circuit.

Thus the grid of the valve will have impressed on it not only the high frequency E.M.F.s due to induction between the coils A and B, but also the audio frequency E.M.F.s due to speech.

The effect of the speech current is to vary the grid potential relatively to its normal potential with the microphone idle, and since the grid potential reacts upon the primary and aerial current by means of the valve and the coils A and C, it is clear that the amplitude of the aerial current, instead of remaining constant, will be changed in accordance with the frequencies of vibration of the telephone diaphragm.

The advantage of this type of transmitter is that the telephone need only be of low power capacity.

**539.** When higher powers are required in transmission, it is usual to pass the speech currents through some form of note magnifier circuit, as in Fig. 308.

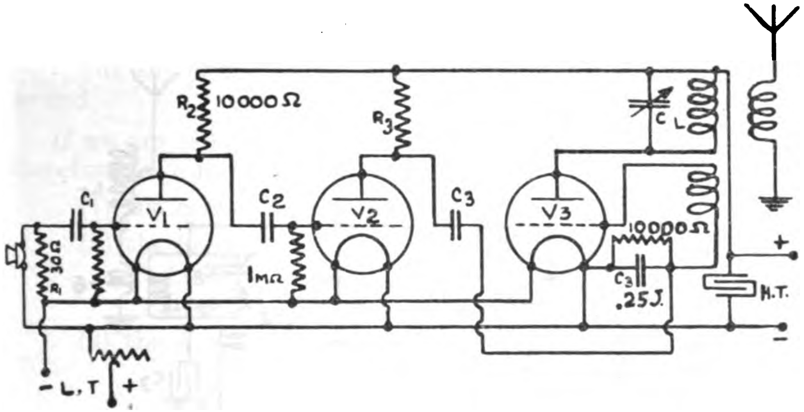


FIG. 308.

The valves $V_1$ and $V_2$ are used as note magnifiers, resistance-capacity coupled, while $V_3$ is the oscillating valve.

The microphone has a resistance of about 30 ohms, and is connected in series with a fixed resistance of 30 ohms, across the filament heating battery. When the microphone is spoken into, its resistance varies and consequently the voltage at the point of connection to the 30-ohm resistance varies.

The amplitude and frequency of these variations in voltage are proportional to the amplitude and frequency of the sound waves impressed on the microphone.

These audio frequency variations of voltage, amplified by valves $V_1$ and $V_2$, are impressed *via* the condenser $C_3$ on the grid of the oscillating valve $V_3$, and so modulate the oscillatory current in the desired manner.

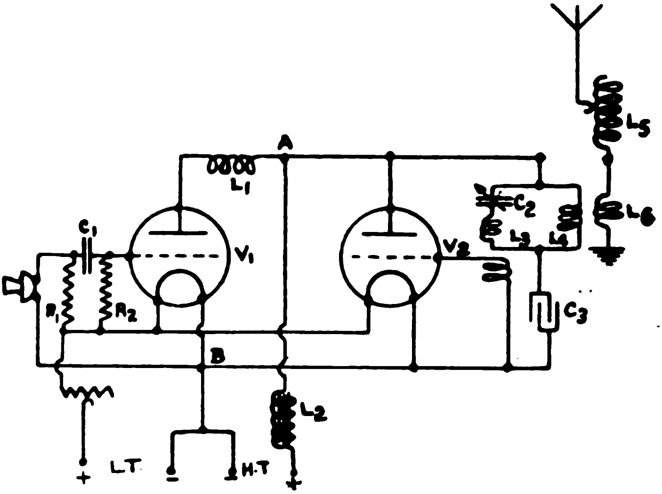
**540. Modulation of Anode Voltage.**—In this arrangement, Fig. 309, the oscillator valve $V_2$ maintains a high frequency oscillation in the primary circuit $L_3$ $C_2$ $L_4$ and aerial circuit. When the micro-phone is idle the h.t. voltage applied between the points A and B will be of constant value, and the aerial oscillation will consequently be of constant amplitude.

When, however, the microphone is spoken into, the grid voltage and anode current of the modulator valve $V_1$ will be varied at audio-frequency. Consequently, the H.T. supply will be called on for a current varying at audio-frequency, which current must flow through the iron-cored inductance $L_2$.

Since the impedance of this coil is high at audio-frequency, it follows that there will be large audio-frequency potential variations across it, and thus the P.D. between the points A and B will be varied at audio-frequency and in time with the vibrations of the microphone diaphragm.

As a result of this, the amplitude of the radio-frequency currents in primary and aerial circuits will be varied at audio-frequency.

The duty of the choke coil $L_1$ is to pass audio-frequency, but to bar radio-frequency variations in the valve current, and so prevent the modulator valve $V_1$ from taking from the primary circuit any of the high-frequency power which the oscillator valve $V_2$ is supplying to it.



*Anode-Voltage Modulation Circuit.*

Fig. 309.

**541. Sidebands.**—Let us examine the nature of the modulated wave a little further.

Suppose the frequency of the carrier current is $f_c$ and its maximum value $I_c$.

Then the aerial current due to the carrier alone will be—

$$i = I_c \sin 2\pi f_c t \text{ (\textit{see} Ch. V., para. \textbf{214}).}$$

When this wave is speech-modulated, there is blended with it an audio-frequency current.

Let us say that the frequency of this audio-current is $f_s$ and its maximum value is $I_s$.

Then the equation of the speech current which modulates the carrier current is :—

$$i = I_s \sin 2\pi f_s t.$$

During modulation these two current waves are blended together, and the resultant modulated wave is a combination, the components of which can easily be determined by mathematics.

The resultant equation shows that the modulated current is a blend of three components :—

(1) the carrier frequency ($f_c$).

(2) the carrier frequency + the speech frequency ($f_c + f_s$)

(3) the carrier frequency — the speech frequency ($f_c - f_s$)

Now, we have in fact to transmit not one speech frequency only, but any of the whole band between 300 to 3,000 cycles per second.

If we are using a carrier frequency of (say) 100,000, we shall therefore have to transmit—

(1) the carrier frequency of 100,000.

(2) the band from 100,000 + 300 = 100,300 to 100,000 + 3,000 = 103,000, which we may term **the upper sideband.**

(3) the band from 100,000 — 300 = 99,700 to 100,000 — 3,000 = 97,000, which we may term the **lower sideband.**

This makes one point clear—that the receiving circuit must not be too selective. It will evidently be required to receive frequencies of 97,000 and 103,000 equally well, which a sharply-tuned circuit would not do.

An indication that a receiving circuit is too sharply tuned is that the speech sounds low and drummy.

It is interesting to note that by the use of suitable filter circuits it is possible to eliminate the lower sideband and the pure carrier frequency component, and transmit the speech on the upper sideband only.

As this method has no immediate service application, the explanation is omitted.

**542. Duplex Working.**—The simplest **send-receive** system is to employ a relay switch which connects the aerial to the receiving circuit when speech is finished, and simultaneously stops the transmitter from oscillating by switching off the H.T. supply.

The relay switch would be operated by some simple "push-control" near the operator.

This arrangement has the big disadvantage that when one station is transmitting the other station cannot interrupt (say) to ask for a repetition.

A great improvement is to arrange for simultaneous transmission and reception.

This is termed "Duplex" working.

It is obviously not an easy matter so to arrange the receiving circuit that it is uninfluenced by the oscillation of the transmitting circuit.

The systems used fall under three heads—

(*a*) Employment of different waves by the two stations, and of selective devices to effect separation.

(*b*) The balancing-out of the effect of the transmitting current on the receiving circuit.

(*c*) The use of the transmitter current to heterodyne the received current at supersonic frequency.

Since these methods are not used in H.M. Service at present, and since radio-telephony itself is little used, on account of its inherent drawbacks, no description of these methods will be given here.

It should be noted, however, that it is quite common practice to use a radio-telephone system which can be connected to, and employed in the same manner as, the ordinary line telephony system.

## CHAPTER XV.

## THE ÆTHER AND THE ATMOSPHERE.

**542.** It is now time to consider more carefully what happens to the æther wave after it leaves the aerial.

Certain general facts have been stated in the earlier chapters. These are :—

The whole universe including the earth is assumed to be surrounded and permeated by a medium termed æther.

The æther can be set in vibration by electron movements, by reason of the electric fields associated with the electrons.

All free movements of the æther travel at the same rate, viz., *$3 \times 10^8$ metres per second.

Different rates of electron movement produce æther waves of different length, viz., " X " Rays, light, Hertzian or wireless waves, &c.

The energy conveyed by the different æther waves can be converted into heat energy if suitable receivers are used.

When a condenser is charged and discharged a state of varying strain is produced between its plates, and " lines of electric strain " spread out from it.

When a current is varied through an inductance, " lines of magnetic strain " in the æther are produced.

When an aerial circuit is set in oscillation, the energy imparted to it is transferred rapidly backwards and forwards between the capacity and inductance of the aerial, and a wave due to alternate electric and magnetic strains—termed an electro-magnetic wave—is propagated.

Any substance, or medium, which acts as an insulator or dielectric, **passes** a wireless wave readily; *i.e.*, the electric and magnetic forces pass freely through it without losing any of their energy.

Any substance possessing conductive properties absorbs energy from the wave, because movements of electrons take place in it, and the energy of the wave is converted into heat energy; thus a sheet of soft iron is almost a complete barrier to a passage of an electro-magnetic wave.

**543. Radiation.**—In a wireless transmitting or receiving set either the condenser or the inductance coil is made of large dimensions. In the first case, it is termed an "open" aerial, and in the second a "loop" aerial.

---

* This figure is an approximation. The figure which is generally accepted as being accurate is $2 \cdot 9982 \times 10^8$ metres per second.

The aerial effects the transfer of energy between the wireless circuit and the æther.

When an aerial circuit is set in electrical oscillation, some of the energy of the oscillation is expended in the generation of radiated waves of energy which spread out over the surface of the world.

Similarly, when a mechanical oscillator, such as a piano string, is set in oscillation, some of the energy of the oscillation is expended in generating sound waves.

In neither case, however, is all the energy so expended: otherwise the oscillation would be damped out immediately.

It is not an easy matter to explain without the help of mathematics, the exact process of electro-magnetic radiation.

To start with, let us take the case of an aerial such as is used in an aeroplane, consisting of a trailing wire aerial and an earth comprising all the metal work of the plane (Fig. 310 (*a*)). This may be simplified into the form shown in Fig. 310 (*b*).

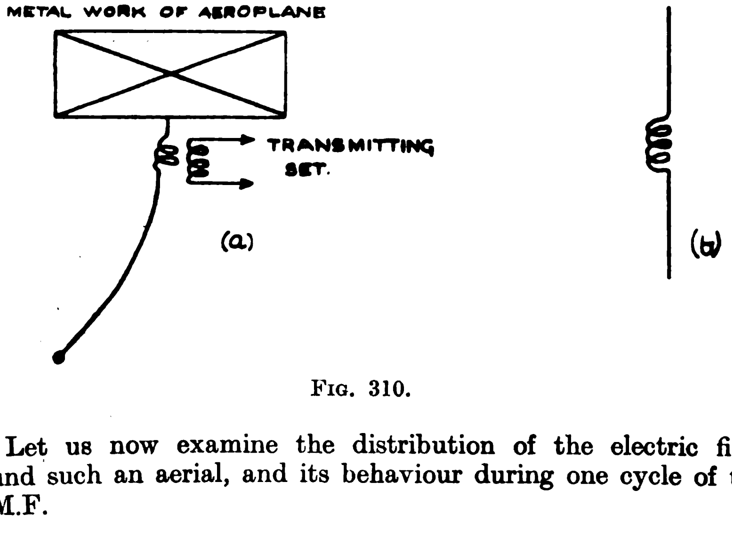


Fig. 310.

Let us now examine the distribution of the electric field round such an aerial, and its behaviour during one cycle of the E.M.F.

When this circuit is set in oscillation, then at the moment when the condenser is fully charged and the current is zero, we may imagine lines of electric strain to be connecting each positive ion on the upper plate to its "opposite number"—a negative ion on the lower plate, as in Fig. 311 (*a*).

When the moment of maximum E.M.F. has passed, current will flow downwards.

The ends of the lines of force slide together along the wires (as in Fig. 311 (*b*) ) and finally unite as in (*c*). The current now goes on flowing and the charges in the condenser are reversed, and new lines of force are produced with reversed polarity, the first electric disturbance having been snapped off in the form of closed loops.

The first disturbance is forced outwards by the birth of the new electric field, for the directions of the lines in the inner surface of the first and the outer surface of the second are the same.

As the current oscillates in the circuit, a series of closed loops of **electric strain** are flashed off into space, each repelling its predecessors to make room for the latest born; each set of loops representing lines of force in opposite directions to the set of loops next in front and in rear.

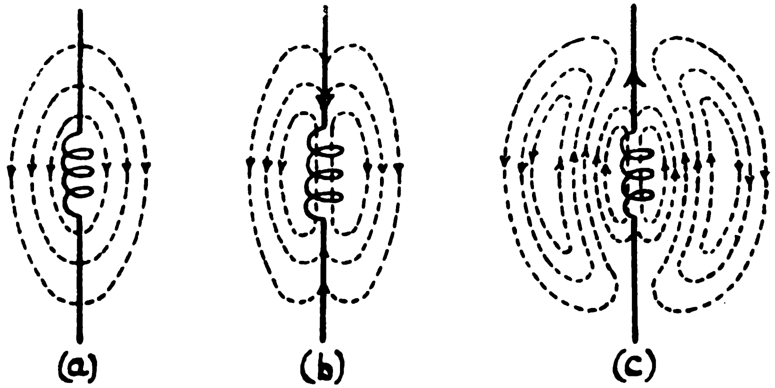


Fig. 311.

Similarly we must imagine the wires to be surrounded by rings or ripples of **magnetic strain**, whose intensity will vary with the current strength and whose direction will alternate as does the current.

Further, these magnetic lines of force are horizontal, being in a plane at right angles to the current-carrying wire, and consequently at right angles to the electric lines of force.

This type of oscillation, causing symmetrical loops to travel outwards, is called a "free-wave" system, and is that which results from using an oscillator excited in the middle, as in an aeroplane aerial.

**544.** The case of an earthed aerial wire excited at its lower end presents a different form of electrical disturbance, as shown in Fig. 312.

The effect is the same as if only half of the aeroplane oscillator had been regarded, at any rate when the waves have travelled some little distance from the aerial.

If the aerial consists of a capacity area at the top with the feeder symmetrically placed, the distribution of the electric and magnetic fields is somewhat as shown in Fig. 312.

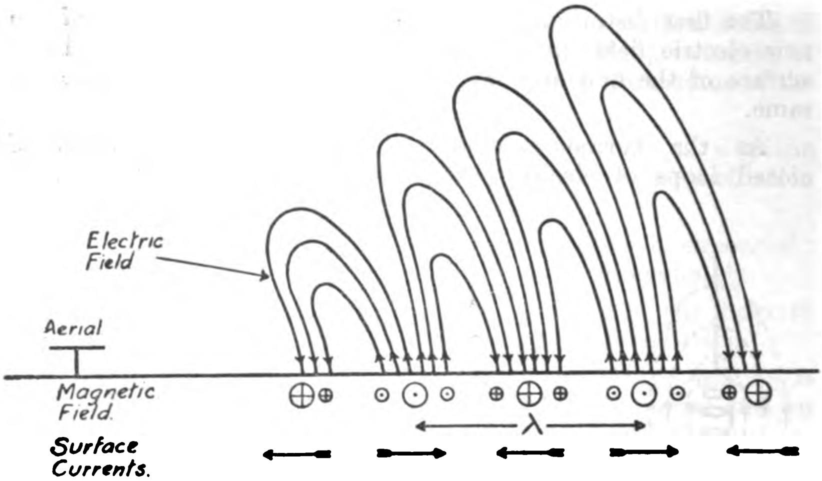


Fig. 312.

The full lines represent the electric field spreading out in the form of annular loops of ever increasing height but constant width.

These loops are accompanied by horizontal bands of magnetic flux spreading out from the aerial with the electric loops.

The maximum magnetic flux density occurs when the electric field is the greatest.

In the surface of the earth there will be circular bands of currents flowing alternately radially inwards and outwards.

The wave-length, $\lambda$, will be the distance from one point of maximum electric or magnetic field to the next maximum in the same direction.

**545. Radiation and Induction.**—It is important to distinguish between "radiation" and "induction."

The principles of induction have already been explained in Chapters III, V and VI.

Radiation is a moving disturbance of the æther, the energy associated with which does not return to the radiator.

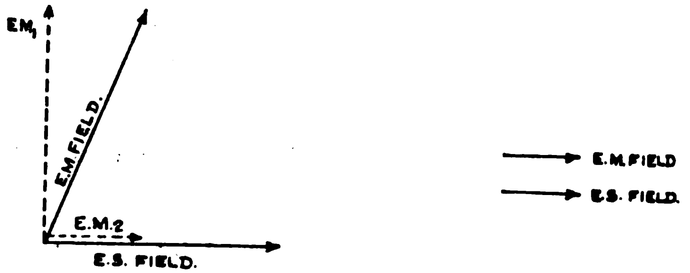
Near the aerial, a conductor is influenced by both the inductive and radiated field, and the intensity of the inductive field would be the stronger.

It can be shown mathematically that at a distance equal to $\frac{\lambda}{2\pi}$ their intensities are equal, while at 5 to 7 wave-lengths away the inductive field is negligible. The intensity of the radiated field varies inversely with distance, whereas the intensity of the inductive field varies inversely with $(\text{distance})^2$

In the region of direct inductive action, the electric and magnetic fields are nearly 90° out of phase.

In the radiated field, however, they are no longer so, but one field is in phase with the other, thus representing a definite expenditure of energy by the transmitter.

This is in accordance with our previous experience (Chapter V, para. **260**), that when electrical energy is being expended, current and volts, with their attendant fields, are in phase, and further that the energy radiated from an aerial corresponds to a definite resistance component in the aerial circuit termed "Radiation Resistance" (*vide* Chapter VI, para. **333**, and Chapter XVI, para. **557**).



(a)
FIELDS NEAR AERIAL ARE NEARLY 90° OUT OF PHASE.

(b)
FIELDS IN FREE WAVE ARE IN PHASE

FIG. 313.

Figures (*a*) and (*b*) represents the phase relations of the electric and magnetic fields (*a*) in the immediate neighbourhood of the aerial (*b*) in the free wave.

In Fig. 313 (*a*), the magnetic field is the resultant of two components, viz., E.M.$_1$, 90° out of phase with the electric field, and corresponding to the true inductive field, and E.M.$_2$ in phase with the electric field, and corresponding to the current in phase with the E.M.F., which together represent the total effective losses in the aerial circuit.

The inductive field E.M.$_1$ rapidly diminishes and soon becomes inappreciable, as stated above; outside the region of direct inductive action we are left with the two fields in phase as shown in figure (*b*).

**546. The Path of the Æther Wave.**—If the æther wave had to travel through æther only, like the sun's rays on their way to the atmosphere surrounding the earth, they would have a very easy passage.

The sun's rays are, however, affected in all sorts of ways when they enter the atmosphere of the earth.

They are absorbed by fog, screened by clouds, refracted by the layers of atmosphere of different density, as at sunrise and sunset, and reflected from polished surfaces.

A wireless wave is liable to similar vicissitudes in its passage over the surface of the globe.

A transmitting aerial radiates energy not only horizontally over the surface of the earth, but also upwards, the strength varying from a maximum horizontally to zero vertically: we must therefore consider the nature of the atmosphere not only just above the earth's surface, but also at great heights, since it has been shown experimentally that it is only thanks to peculiarities of the upper atmosphere that the greater ranges are obtained, owing to the return to earth of a great deal of the energy which is radiated upwards.

**547. The Atmosphere.**—The total depth of the shell of air that envelopes the earth is not more than about 100 miles. Its depth is therefore small when we remember that the earth's diameter is 8,000 miles, and that we can easily transmit signals for distances of 2,000 miles.

Up to a height of about 60 miles the air has the same composition as at the surface of the earth, but it becomes less and less dense.

Above this height the ordinary constituents of the atmosphere disappear and are supposed to be replaced by hydrogen and helium and possibly other light gases, although there is no positive evidence on this point.

**548.** Now the electrical properties of the atmosphere vary greatly with height.

At the surface of the earth, air is a perfect insulator or dielectric: consequently, wireless waves pass through it without appreciable loss of energy.

At the height of 60 miles, the atmosphere is probably completely ionised or electrified: that is to say, the gases are composed of charged molecules (or positive and negative ions), and free electrons.

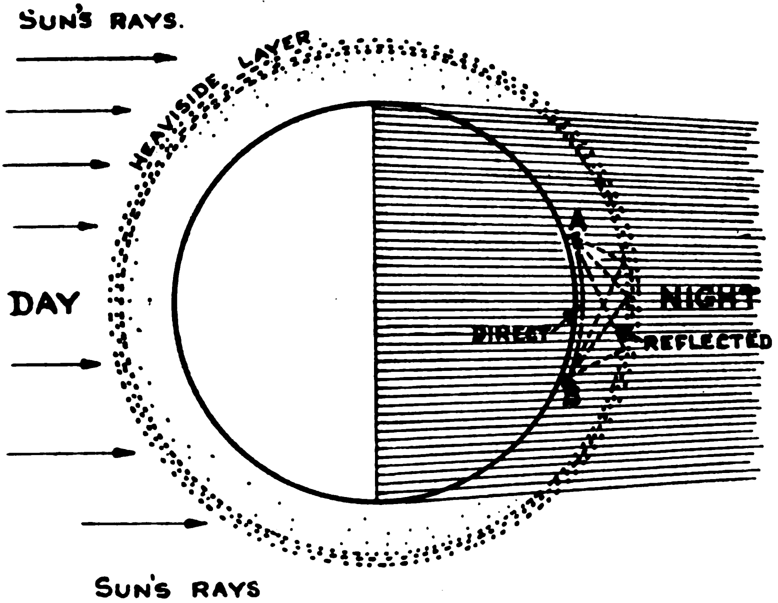
A well ionised gas possesses all the properties of a very good conductor: so good, in fact, that a layer of it only half an inch in thickness, will not allow a wireless wave to pass through it.

The reason of this ionisation is partly the action of the sun's rays, and in particular that of the ultra-violet light component, and partly the negatively charged dust projected from the sun and transmitted to the earth through the agency of light pressure.

This ionised layer is termed the "**Heaviside Layer,**" in honour of the physicist who first postulated it.

The layer does not always exist in the form of a shell concentric with the earth, with smooth surfaces, but more probably in the form of large clouds of gas, which act as reflectors and refractors for wireless waves.

In addition to the above permanent ionization, the atmosphere at a lower level is also liable to irregular ionization by day, by the action of the sun's rays. This is indicated in Fig. 314 by the irregular specks on the sunny side of the earth.



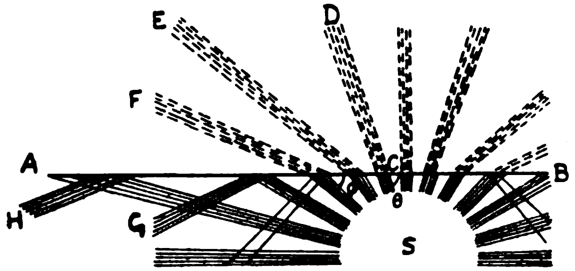
*The earth, showing the action of the sun's rays in producing an electrified layer.*

FIG. 314.

By night these ions combine to form neutral molecules, so leaving the middle atmosphere deionised, except for local patches such as thunder clouds.

**549. Reflection and Refraction.**—A wireless wave, falling upon a partially ionised layer will be either reflected or refracted (bent) or both, according to its angle of incidence. We will now examine the meaning of these two expressions.

Fig. 315 illustrates waves emanating from a source S, striking the surface A B of a layer of denser electrification. The beam C striking A B at right angles is neither reflected nor refracted,



*Reflection and refraction.*

FIG. 315.

but travels straight on. The beams D and E are refracted or bent. (An illustration of this can be seen by partly immersing a stick in water. It will appear to be bent, if viewed from an angle, at the point where it enters the water).

The beam F is partly reflected and partly refracted. The beams G and H are wholly reflected.

Further, the angle of refraction depends on the wave-length: the shorter the wave the more sharply is it bent towards the surface.

**550. Irregularities in Transmission.**—In view of the irregular ionization of the atmosphere, the great irregularities in wireless transmission are not surprising.

The method in which a wireless wave travels round the globe, and the way in which it may be assisted or hindered by reflection and refraction from ionized strata of air, is inferred by deduction from evidence provided by various phenomena.

The following phenomena in wireless transmission are well-established, and their explanations are as given below:—

(*a*) Greater range is always obtainable by night than by day with short waves*: long waves have practically the same range by day and night.

By day the short (high frequency) wave suffers heavily in its passage through the irregularly ionized patches of the middle atmosphere, whereas by night the wave is reflected onwards by the Heaviside layer.

The long wave loses less energy in its passage through the middle atmosphere by day; hence the difference between day and night transmission is less.

(*b*) One wave-length may be much better than another for communication between two given points and the best wave-length may alter according to the time of day.

This can only be explained on some theory of irregular refraction.

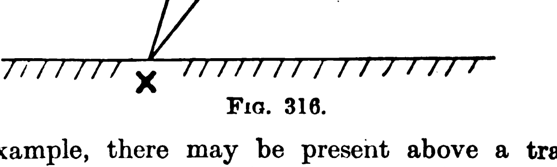


Fig. 316.

For example, there may be present above a transmitting station X (Fig. 316) a layer of ionized air inclined at some angle dependent on the height of the sun. Wireless waves of a certain length may be so refracted that a large portion of the transmitted energy does not reach the earth's surface at the point where it is wanted, but is dissipated in the middle atmosphere.

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* But recent experiments have shown that this statement does not apply to waves below 100 metres.

A change in wave-length may so alter the angle of refraction, that the energy is concentrated at the receiving station instead.

(*c*) The wave front of a wave arriving from a long distance is inclined to the earth's surface at some angle from the vertical.

This occurs because the foot of the wave is dragged back by earth resistance.

(*d*) Long waves are better than short ones in mountainous country by day, but there is not much difference by night.

This may be explained by saying that by night, both waves are reflected sharply back from the Heaviside layer, whereas by day only the long waves are bent back sharply enough to penetrate the valleys.

(*e*) "**Fading.**"—Signals on short wave-lengths received from a given transmitting station often vary rapidly in intensity by night, all circuit adjustments at the transmitting and receiving stations remaining constant.

This is attributable to variations in the absorption of these waves as they travel along the Heaviside surface. By day the waves do not reach the Heaviside layer, on account of the ionization in the middle atmosphere, and they are therefore more constant in their results.

(*f*) Intercommunication between two stations is always worst when one station is in darkness and the other in daylight.

This is because the zone where the change from light to darkness is taking place, may be the scene of very violent and irregular ionization or recombination of ions and electrons. This zone may disperse the waves in all directions.

**551. The Part played by the Earth.**—We have seen previously that the bases of the electro-magnetic waves move outwards from the aerial over the surface of the earth, and also that circulating currents are set up in the ground.

The surface of the earth is not everywhere a good conductor of electricity. The sea and moist soil are better conductors than dry stone.

In some places the surface materials of the earth are in fact good insulators.

The attenuation—or weakening—of the electric wave is on this account very different over different parts of the surface of the earth—depending on the fact that there is a greater or less penetration into the insulating portions and a greater or less absorption of energy at the poorly conducting portions.

For example, a theoretical calculation (by Zenneck) shows that a station having a range of 1,000 miles over a perfectly conductive expanse, would have a range of—

920 miles over sea water,
700 ,, ,, fresh water or very wet soil,
560 ,, ,, wet soil,
270 ,, ,, damp soil,
150 ,, ,, dry soil,
55 ,, ,, very dry soil,

and these figures accord very well with practical experience.

Short waves suffer much more in passing over land (even flat land) than do long ones. This is due to the greater losses suffered by the high frequency currents.

The useful "layer" of earth becomes shallower and the consequent resistance greater.

An ordinary high frequency current will not be perceptible at a greater depth than 15 metres in damp soil. Damped wave trains will penetrate even less than this amount.

It is quite possible to receive signals on an insulated wire buried in the ground.

The depth of penetration in salt water is about 5 metres—depending upon the amount of salt in the water.

As a general conclusion, one expects to get the longest ranges over sea, and range falls off if dry ground intervenes.

Great difficulty occurs in communication between two stations which have jungle or dense undergrowth intervening, especially if the jungle grows close up to the station.

A tremendous absorption of energy occurs; moreover, there seems to be a layer of air, level with the tree tops, at the same potential as the earth, and the wave travels along the surface of this, and does not influence a receiving aerial, unless the latter be a good deal higher than the trees.

**552. Screening.**—It is a well-known fact that if a ship is lying close to a very high piece of land, or in a land-locked harbour surrounded by high cliffs, her reception of signals is greatly diminished, while if she steams away clear of the land by a few miles, she picks up signals once more.

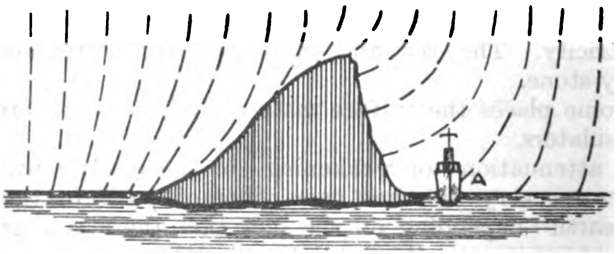

Fig. 317.

This occurs for two reasons:—

(*a*) The electric field of the æther wave is deflected by the land as illustrated in Fig. 317. This means that the electric lines of force acting on the aerial of the ship (A) are in a horizontal instead of a vertical direction, and thus are made very ineffective.

(*b*) A great deal of the available energy in the portion of the wave front with which the ship is concerned is wasted in the high ground.

This effect is very noticeable if the soil is very permeable, *i.e.*, if it contains a high percentage of iron ores.

A similar screening effect takes place if a ship is lying under a big crane, or a bridge like the Forth Bridge.

**553. Atmospherics or Strays.**—Since the beginning of the world, æther waves of the order of length used in wireless telegraphy have been and are continuously traversing its surface, but have only been noticed since the inception of wireless telegraphy.

They are generally known as "atmospherics," "strays" or "X's"; disturbances known as "statics" are a special variety.

Atmospherics have a very variable but generally long wave-length.

Their damping is heavy, and their shock effect is severe.

When they encounter an aerial they set it oscillating at its own natural frequency and are consequently very difficult to cut out; they may be reduced in strength by the use of some limiting or balancing device, and as they are non-musical they can be over-read by a skilful operator if they are not too severe.

The following is a brief summary of the known facts.

**Classification.**—For convenience, atmospherics are classified as follows:—

(a) **Hissing.**—An almost continuous noise, especially marked during snow or when heavy clouds are passing over the aerial.

(b) **Clicks,** or very short noises.

(c) **Grinders,** a type exactly described by the word given.

The distinction between the various classes, however, does not correspond with any precise idea of their origin and is not always exact.

**Annual Periodicity.**—In general, atmospherics appear to be more frequent and severe in summer than in winter.

Actual measurements in England indicate a maximum in June and a minimum in March.

In the East Indies, the maxima occur during the changes of the monsoon. A minimum occurs during the N.E. monsoon and a less marked minimum during the S.W. monsoon.

*Daily Periodicity.*—As a rule, atmospherics are worst from just before sunset till about 1 a.m., after which they gradually decrease. This effect varies, however, in different parts of the world.

*Direction.*—Atmospherics which have a distant origin, as opposed to those generated locally, appear to come from the direction of the equator.

More locally, atmospheric disturbances appear to have their origin in mountainous regions.

*Nature.*—Atmospherics have either the nature of a shock, *i.e.*, they produce in aerials an E.M.F. of short duration reaching its maximum in a very short time, or else of a band of frequencies which it is impossible to eliminate by selective tuning. The former is of a similar type to that which would be produced by the sudden discharge of a condenser.

In general, the severity of atmospheric interference increases with the length of the wave to which the receiving aerial is tuned.

On the other hand, observations made at Honolulu showed that stations working on a short wave-length experienced numerous and violent disturbances, while neighbouring ones on longer waves were less troubled.

Experiments were carried out by Mr. Watson Watt in England actually to measure the shape and duration of the discharges. They were found to fall roughly under two headings—aperiodic and semi-periodic. The former were unidirectional, and the latter had a second weaker impulse in the opposite sense to the first half cycle.

*Origin.*—One class of atmospheric disturbance is due to lightning flashes of local origin.

As regards those coming from a distance, however, which occur even when the sky is perfectly clear, it has already been pointed out that the atmosphere is by no means at a uniform zero of potential, but that large patches of it accumulate excess positive and negative charges.

In addition to ionization by the sun's rays, local action by wind or rain may also produce similar results.

For example, when a wind blows through cloud or rain, both are electrified, the water drops positively and the air negatively; when this occurs on a large scale, several thousand feet above the earth's surface, in conditions favourable to the formation of large clouds, we get "thunder weather."

Again, evaporation is always accompanied by electrification of the liquid and vapour, so that in the tropics, there is always a disturbed electrical state.

When, again, a wind blowing over a sandy or dusty plain raises clouds of dust, there is intense electrification. The potential of the dust, as a system of particles, is raised by their separation. The necessary energy is supplied by the wind.

Both positive and negative ions are formed which collect on the clouds and earth respectively, leading, when the potential difference is high enough, to lightning discharges between them.

**554. Statics.**—Statics are a special variety of atmospherics, and are due to electrical charges accumulated by the aerial like a lightning rod. A charged cloud approaching an aerial produces by static induction a charge of opposite sign in the aerial.

For this reason it is always inadvisable to leave any aerial insulated from earth by a receiving condenser, as a charge is liable to accumulate and puncture the condenser (*vide* para. **438**).

# CHAPTER XVI.

## AERIALS, EARTHS AND INTERFERENCE.

**555.** We will now consider the principles and design of the aerial wire system known as the " Aerial."

In general, aerials differ greatly according to whether they are intended for transmission or reception.

### Transmitting Aerials.

**556. Losses.**—The following table indicates graphically the various losses in which is expended the energy supplied to an aerial by the wireless power plant.

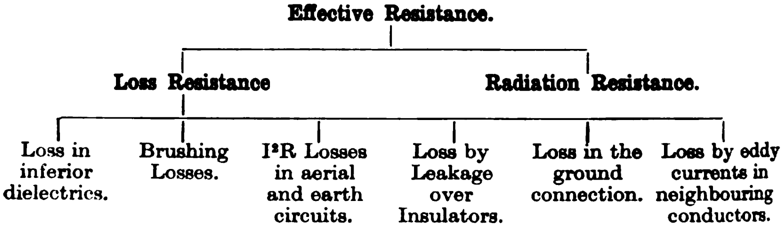
Effective Resistance.
Loss Resistance
Radiation Resistance.
Loss in inferior dielectrics.
Brushing Losses.
I²R Losses in aerial and earth circuits.
Loss by Leakage over Insulators.
Loss in the ground connection.
Loss by eddy currents in neighbouring conductors.

**Table of Losses in Aerial Circuit.**

These various losses, and the methods of minimising them, may now be discussed in detail.

**557. Radiation Resistance.**—The radiation resistance is that component of the aerial resistance which, when multiplied by the square of the aerial current ($I^2R$) measures the power radiated.

The radiation resistance ($R_r$) of a flat-topped aerial is given by the expression

$$R_r = 1600 \frac{h^2}{\lambda^2}$$

where h is the " radiation height " of the aerial and $\lambda$ is the wave-length in use (both being measured in the same units).

Height is therefore a factor of great importance in the design of an aerial.

It will also be noted that the radiation resistance varies inversely with the square of the transmitted wave-length, so that more energy is radiated on short waves than long ones.

Practically, this is true until the fundamental wave-length of the aerial is reached; below this, the losses introduced by the presence of a series condenser in the aerial circuit outweigh the gain in radiated energy due to the shorter wave.

The actual range obtained is not by any means proportional to the radiated energy, since short waves are absorbed by the atmosphere to a much greater extent than are long ones, especially by day.[*]

The "Radiation Height" of an aerial system is defined as "the height of an ideal aerial system consisting of an elevated capacity connected to a perfectly conducting earth by a feeder having no capacity, which for the same aerial current and the same frequency, would produce the same electric field at any given distance as the aerial system in question."

The radiation height is not easy to measure, and can, in fact, only be determined satisfactorily by quantitative measurements of the actual radiation, taken on a receiving aerial in the neighbourhood.

It is always less than the actual height, particularly in ships, where it is decreased by the proximity of stays, funnels, and other metallic substances.

A correction may be applied to the actual height in order to take account of the proportion of its length to height, as follows :—

[†]Let L = length of horizontal part for Γ aerials.
= half total length for flat-top T aerials.
Let h = height of aerial.

Work out the ratio $\frac{L}{h}$.

Then the "aerial form factor" (*a*) may be determined from the following table :—

| $\frac{L}{h}$ | a. | $\frac{L}{h}$ | a. |
|---|---|---|---|
| 0·0 | 0·639 | 1·5 | 0·940 |
| 0·1 | 0·696 | 2·0 | 0·958 |
| 0·2 | 0·741 | 3·0 | 0·979 |
| 0·3 | 0·777 | 4·0 | 0·987 |
| 0·4 | 0·806 | 5·0 | 0·993 |
| 0·5 | 0·830 | 6·0 | 0·996 |
| 0·6 | 0·850 | 7·0 | 0·998 |
| 0·7 | 0·867 | 8·0 | 0·999 |
| 0·8 | 0·881 | 9·0 | 0·999 |
| 0·9 | 0·893 | 10·0 | 1·0 |
| 1·0 | 0·904 | — | — |

The corrected height of the aerial = a × h.

This factor gives a fair approximation to the radiation height for shore station aerials and for merchant ships with wooden topmasts of equal height, small metal superstructures, and the feeder well away from the funnel.

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[*] But *see* footnote to p. 404.

[†] B. Hoyle: "Standard Tables and Equations in Radio Telegraphy."

In ships where these conditions do not obtain it is of no value, and the radiation height can only be determined by actual measurement of the radiation.

The **power** radiated from an aerial

$$= I^2 \times 1600 \frac{h^2}{\lambda^2} \text{ watts.}$$

A practice has arisen of indicating the power of a station in "metre-amperes," *i.e.*, the radiation height multiplied by the current at the foot of the aerial.

This expression is termed the "**Radiation Constant.**"

It is clearly a more accurate method of description than that by which a station is referred to as being of so many kilowatts.

The latter expression leaves doubt as to whether the power input to the generator, to the wireless plant, or to the aerial, is meant.

The radiation resistance necessitates an expenditure of energy by the transmitter, but it is a loss we wish to encourage, and it should be as large as possible in proportion to the other losses.

**558. Loss in Inferior Dielectrics.**—This loss is due to the hysteresis phenomenon (*see* para. **138**) in all dielectrics, and more especially in inferior dielectrics such as wood, concrete, masonry, trees, &c., which may happen to be near the aerial and hence are acted on by the electrostatic field around the aerial.

The air itself may be a bad dielectric when smoke or funnel gases are present, as they partially ionise the air and decrease its dielectric efficiency.

**559. Brushing.**—"Brushing"—as distinct from "sparking"—is a phenomenon with which every telegraphist is familiar; it is manifested by a silent bluish discharge from any high potential point in the aerial circuit in the direction of the nearest earthed object.

It indicates that the dielectric of the air in the neighbourhood of the conductor is breaking down, and is being ionized.

If a single wire were used to feed an aerial it would brush heavily, showing that it was overloaded. It is for this reason that multiple wire feeders are used—to distribute the load over several conductors in parallel.

As soon as an aerial starts to brush it is no use increasing the aerial current; the transmitting range will not be increased, and at night the position of the ship will be disclosed.

It is found in practice that the limit is reached when the peak value of the oscillatory potential in the aerial reaches about 100,000 volts.

An aerial brushes most vigorously from its ends and from sharp points and angles.

If the feeder is immediately abaft the funnels, the smoke and funnel gases will considerably increase its tendency to brush, as they partially ionise the air and decrease its dielectric efficiency; they will also tend to make the aerial wire brittle, and will have a bad effect on spreader discs.

For this reason it is best, when possible, to feed the aerial before the funnels, especially in destroyers and other small craft with low aerials.

The greater the capacity of the aerial, the less inductance will be required for tuning to any particular wave, and consequently the less the oscillatory potential of the aerial above the deck insulator ($V = I\sqrt{\frac{L}{C}}$, (*see* para. **241**) ).

**560. Conductor Losses in Aerial and Earth Circuits.**—*The Aerial.*—The method of construction of the aerial must be a compromise between the requirements for good conductivity and those for mechanical strength.

In order to keep down " skin effect," it is better to use stranded wire than one solid conductor.

Bare iron wire should not be used, as, owing to its permeability, " skin effect " is very marked.

Galvanised wire is better, as the current will flow over the galvanised skin; but it is not so good as copper wire.

The best material for an aerial is phosphor-bronze wire, but it is expensive.

Insulated wire should not be used, as it becomes covered with a semi-conducting layer of soot which, forming a skin to the wire, would carry a certain proportion of the aerial current, and therefore cause great resistance damping.

In H.M. ships the wire used is copper covered with " anti-sulphuric " enamel, to counteract the corrosive effect of smoke and funnel gases.

The importance of making all joints in the wire with the greatest possible care cannot be too much emphasised.

Although a badly made aerial may send nearly as efficiently as a well made one on account of the transmitting energy being sufficient to " jump " any small break in the continuity of the conductor, yet, when it comes to receiving, the minute currents will be unable to flow through any high resistance junction and great loss of efficiency will ensue.

The best arrangement is to make aerial and feeders continuous throughout, the aerial wires being taken round a thimble and used to form the feeders. This arrangement is the strongest and the most efficient electrically.

It is a troublesome job to make an aerial. Accordingly, whenever a new aerial has to be made it should be made as carefully and strongly as possible, special attention being paid to the measurements of the wire.

If these precautions are taken, the aerial, when once up, will remain up for a very long time without giving any trouble.

The wire should never be soldered at any place which is going to be in a state of tension, for the temper is spoiled by the application of heat and the wire thereby rendered brittle.

All sharp points, roughnesses, burrs, and sharp bends or kinks must be smoothed off or otherwise avoided, because they assist in the leakage of energy in the form of brushing.

*The Earth.*—The method of constructing the earth in ship and shore stations, so as to afford good conductivity, is described later.

**561. Loss by Leakage over Insulators.**—Defective insulation will account for a considerable loss in efficiency, especially on long waves not only when transmitting, but also when receiving,

This is clear from the formula for damping decrement due to faulty insulation resistance

$$\delta = \frac{94}{R}\sqrt{\frac{L}{C}} \text{ (para. 332),}$$

which indicates that the greater the inductance used in tuning the aerial circuit, the greater the voltage applied to points of faulty insulation, and, therefore, the heavier the damping loss due to leakage.

The points where losses are liable to occur are at the insulators in the trunk, at the deck insulator, and at outhaul or strain insulators.

It is, therefore, the duty of the wireless staff to keep all these scrupulously clean, especially after high speed steaming, heavy rain, or bad weather, since under these conditions the insulators will probably be covered with a semi-conducting layer of "stokers," dirt, or dried salt.

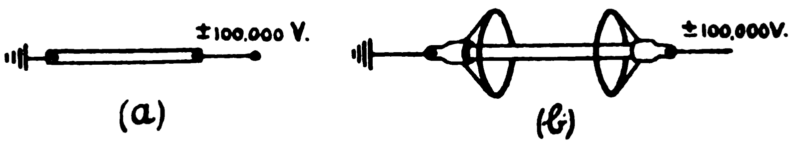


Fig. 318.

Strain insulators are fitted with an "anti-brushing" fitting, as in Fig. 318 (*b*). The reason of this is as follows :—

Suppose we have a plain porcelain rod, as in Fig 318 (*a*), one end of which is connected to earth and the other end to an aerial wire which may have an oscillatory potential of 100,000 volts, there will then be a great tendency for sparking to occur over the surface of the rod. If, however, "anti-brushing" rings are fitted, the electric strain is imposed on the air between the two rings—*i.e.*, over a larger area of dielectric—and the tendency to brush is reduced.

The number of strain insulators used in staying out the aerial and feeders should be kept as low as possible, as each additional insulator provides another possible leakage path in parallel.

**562. Loss in the Ground Connection.**—This is a true ohmic loss. The earth arrangements used in ship and shore stations are described in later paragraphs.

**563. Loss due to Eddy Currents in Neighbouring Conductors.**—Any metallic bodies which, being near the aerial or feeder, are in the direct inductive field, will have heavy currents induced in them.

The magnetic field due to these currents reacts on the aerial by ordinary "transformer" action, and increases the loss resistance.

For this reason the aerial and feeders should be kept as far away from metal as possible.

Similarly, the feeder should be run as far away from, and never parallel to, stays, guys, &c.

In spite of these precautions, currents will be induced in all the stays supporting the masts of a ship or shore station.

These stays may be in one of three conditions :—

(*a*) well insulated from earth and split up into a number of well-insulated sections;

(*b*) connected to earth by a low resistance path;

(*c*) connected to earth by a high resistance path.

For both transmission and reception, condition (*a*) is best, then condition (*b*); condition (*c*) should never be tolerated.

If, therefore, the rigging insulators become so coated with dirt, paint, or tar that they cease to insulate satisfactorily, and cannot be cleaned, they should be short-circuited.

Stays and shrouds should be carefully earthed at the point where they are connected to the hull.

When transmission is taking place in a ship, all the stays, &c., will be set in oscillation at a frequency depending on their length.

Stays should, therefore, be divided up into sections of such a length that minimum interference is caused to reception of short waves.

At a shore station, the best condition is that the masts themselves should be insulated from earth. This is not easy, however, for mechanical reasons.

If the masts are of metal, they should be so placed that the feeder does not have to run near any of them.

**564. Effective Resistance.**—The effective resistance of an aerial has already been referred to (in para. **334**). It is the resistance which is equivalent in its effects to all the various losses which affect the aerial circuit, *i.e.*, it is that resistance which, when multiplied by the square of the aerial current, would equal the power put into the aerial

$$\text{or}\quad \text{Watts} = I^2 R_{\text{eff.}}$$

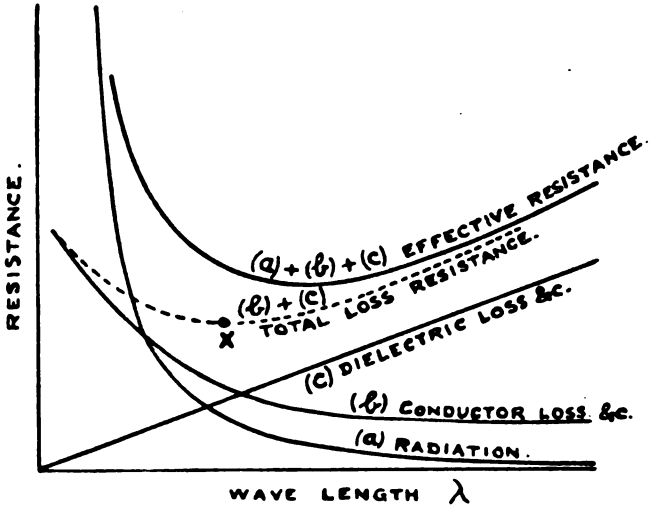
With a given aerial and a given current we find that

(*a*) Radiation resistance varies inversely as $(\lambda)^2$;

(*b*) Resistance corresponding to conductor loss, losses in the earth and losses due to eddy currents, decreases as $\lambda$ increases.

(*c*) Resistance corresponding to dielectric loss, leakage and brushing, increases as $\lambda$ increases.

These facts are illustrated in Fig. 319.



*Graph of aerial losses.*

FIG. 319.

Three curves (*a*), (*b*) and (*c*) are drawn, showing how the above losses vary with $\lambda$.

The dotted curve, illustrating the loss resistance, is obtained by adding curves (*b*) and (*c*) and shows that at some such point as X the total loss resistance is a minimum.

The top curve, showing the total effective resistance, is obtained by adding curves (*a*), (*b*) and (*c*).

This shows that for any aerial there is always a best wave-length at which a given current can be obtained for a minimum power expenditure.

To obtain increased radiation, however, this wave-length should be decreased.

The curve given above is derived from theoretical calculations. It will be found, however, that the "effective resistance" curve of any aerial will have the same general shape as the one given.

**565.** The reduction of loss resistance of aerial systems is especially important in high power long range shore stations.

Long waves are necessary for transmission over long distances, but the useful radiation, which is proportional to the square of the aerial height divided by the square of the wave-length, becomes insignificant compared with the other losses when the wave is sufficiently long.

The reason for this is obvious when we reflect that there is a practical limit to the height of the aerial, say about 250 metres, so that for waves of over 10,000 metres the radiation resistance cannot be greater than $1600 \times \frac{250^2}{10,000^2}$ or 1 ohm, and with longer waves is reduced in inverse proportion to the square of the wave-length.

At 20,000 metres the radiation resistance will be less than 0·25 ohm, and the total resistance of an aerial and earth of ordinary type will probably be of the order of 2 ohms, so that only about $\frac{\cdot 25}{2} \times 100$ or $12\frac{1}{2}$ per cent. of the energy delivered to the aerial is radiated, *i.e.*, is employed in useful work.

The only ways of increasing this efficiency are—

(*a*) to increase the height, by erecting very costly masts, which are in fact unpractical above about 250 metres, and

(*b*) to reduce the losses in the aerial and earth circuits, so that they are small compared with the radiated energy (*see* paras. **570** and **583**).

**566. Capacity of an Aerial.**—The greater the capacity of an aerial, the lower will be its potential above earth for a given charge in it $\left(V = \frac{Q}{C}\right)$. The voltage at which brushing starts is the limiting factor to the power that can usefully be imparted to any aerial. Hence the higher the power we wish to employ, the greater the aerial capacity required.

One must distinguish, however, between "**radiating capacity**" and "**non-radiating capacity.**"

Fig. 320 represents a "T" aerial, fed by a feeder going by a long trunk to an office several decks down. Let us assume that there is sufficient clearance in the trunk to prevent sparking over, but that there is considerable capacity between the feeder and the earthed side of the trunk.

This is denoted in Fig. 320 as $C_2$; we may term $C_2$ the "screened capacity."

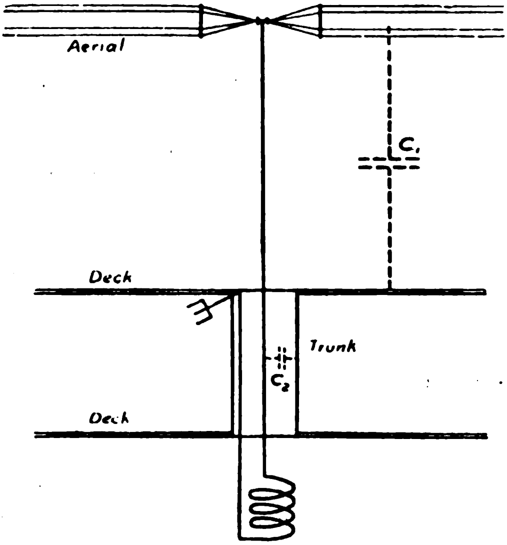


FIG. 320.

If $C_2$ is at all great it will carry a good proportion of the aerial current, which will accordingly not be available to charge up the "radiating capacity" shown dotted as $C_1$.

Remember that if several condensers are joined in parallel, current divides between them according to their relative sizes, most flowing through the biggest condenser.

Thus, if $C_2$ is equal to $C_1$, only half of the available current will do useful work in the aerial, while the other half will flow straight to earth through $C_2$.

In order to give a big "radiating capacity," the overhead or roof system of wires should have the greatest possible area.

As regards the number of wires used, two wires hoisted up parallel to and at a considerable distance from one another will have a capacity nearly twice that of a single wire, but as the wires approach one another the joint capacity becomes less, so that when they are within (say) a foot of each other very little extra capacity is gained by the use of the second wire.

A few wires spaced far apart are better than many wires near together, so far as total capacity is concerned.

It is bad practice to bring a portion of the aerial low down with the idea of getting a big capacity, as this decreases the radiation height (*see* para. **558**).

For an aerial similar in shape to those used with ship installations, the capacity is roughly proportional to the length and independent of the height, after a height equal to the length has been gained.

For low aerials, the capacity decreases as the height increases. Increasing the width of the upper part also increases the capacity, but by no means proportionally.

It is no good making an aerial so big that its fundamental wave is longer than the shortest wave which the aerial is required to transmit, as this would necessitate the use of a series condenser for transmission on that wave, so decreasing the transmitting range considerably.

For short waves, the best aerial is a vertical one, since this gives the greatest radiation height, and consequently good radiation.

The capacity of an aerial will not remain constant unless the aerial be kept hauled out uniformly at all times. Further, it is probable that it will vary if gun turrets near the aerial or feeder are moved, if the awnings are spread or furled and if the decks are wet or dry.

Another possible cause of alteration of aerial capacity, is movement of the feeder by the rolling of the ship, or the action of the wind.

It is therefore, important to keep the feeders as rigid as possible, and to check the tuning at intervals.

**567. Distribution of Voltage in an Aerial.**—If an oscillating charge of Q coulombs is introduced into an aerial, the latter will not be at an equal potential to earth throughout, as neither its capacity nor inductance are symmetrically arranged.

Taking a straight vertical wire, for instance, which is oscillating at its fundamental frequency without any series inductance added, it is obvious that its earthed end must be at earth potential, and therefore its upper end will oscillate to some maximum value above and below earth potential.

This is indicated graphically in Fig. 321 (*a*).

Fig. 321 is just a convenient way of indicating the fact stated above. The distance of the "voltage" curve from the aerial wire is intended to indicate the potential of any particular point in the aerial at the moments when there is no current in the

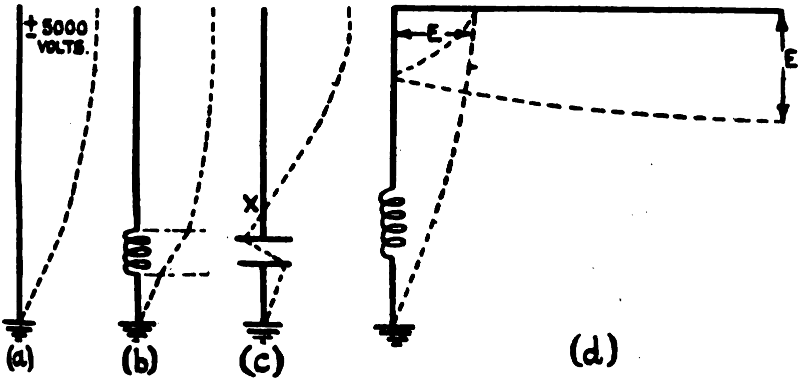


FIG. 321.

aerial, and when its potential above or below earth is at a maximum.

Fig. 321 (*b*) indicates the case of an aerial tuned with an aerial coil to a wave longer than its fundamental. As the inductance of the aerial coil is concentrated, there will be a quick rise in potential up it. For this reason an aerial coil always requires a greater clearance from earth at its upper than at its lower end.

Fig. 321 (*c*) indicates the case of the same aerial tuned by means of a series condenser to a wave shorter than its fundamental.

The " sign " of the aerial charge is reversed by the condenser, and it should be noticed that a low potential point ($X$) is artificially formed at a point a little way up.

Similarly, the voltage distribution in an aerial with a flat roof may be illustrated as in Fig. 321 (*d*), the potential at the extremities being a maximum.

**568. Distribution of Current in an Aerial.**—A converse result for the distribution of current holds good.

In considering the question of current, we take the aerial at the moment when its potential above or below earth is zero, and the current flow is maximum—*i.e.*, at a moment a quarter of a cycle later than that illustrated in Fig. 321.

The oscillatory potential of any point of the aerial circuit causes electrons to move up or down the aerial wire to charge up the aerial capacity to earth at that point.

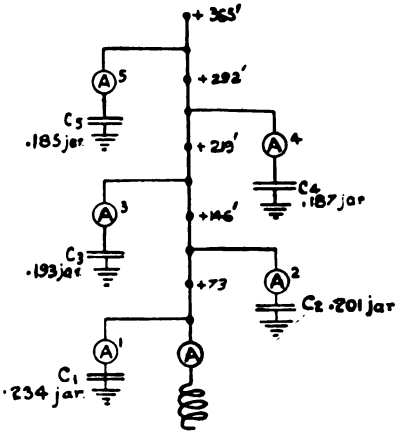


FIG. 322.

**Example 57.**

For example, let Fig. 322 represent a straight wire aerial 365 feet high, divided into five equal parts of 73 feet each.

The capacities to earth at these points are illustrated diagrammatically, as $C_1$, $C_2$, $C_3$, $C_4$ and $C_5$, and their values will be as follows :—

$C_1 = \cdot 234$ jar.
$C_2 = \cdot 201$ ,,
$C_3 = \cdot 193$ ,,
$C_4 = \cdot 187$ jar.
$C_5 = \cdot 185$ ,,
Total - - 1·00 jar.

The various ammeters shown measure the currents charging up these several capacities.

Suppose the ammeter A reads 10 amperes.

Then ammeter $A_1$ will read $\frac{\cdot 234}{1} \times 10 = 2\cdot 34$ amps.

$A_2$ „ $\frac{\cdot 201}{1} \times 10 = 2\cdot 01$ „

$A_3$ „ $\frac{\cdot 193}{1} \times 10 = 1\cdot 93$ „

$A_4$ „ $\frac{\cdot 187}{1} \times 10 = 1\cdot 87$ „

$A_5$ „ $\frac{\cdot 185}{1} \times 10 = 1\cdot 85$ „

$10\cdot 00$ amps.

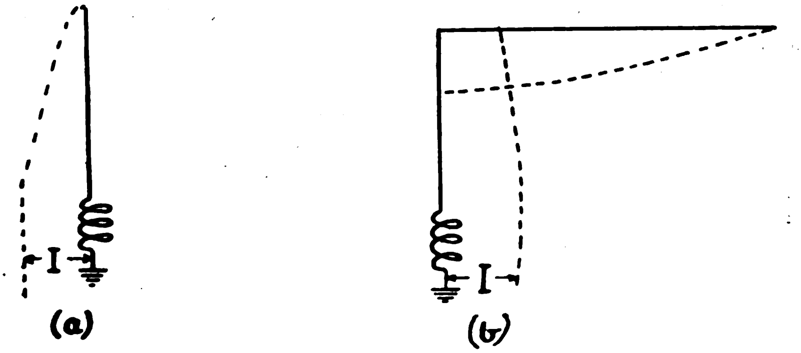
This example is very instructive: it shows—

(*a*) What a large proportion of current flows through the capacity in the lower parts of the aerial.

(*b*) How very important it is, therefore, to have a low-resistance conductor in the lower part of the aerial.

(*c*) How totally misleading a large reading on the aerial ammeter may be if the aerial feeder is carelessly run so as to have a large capacity to earth.

It must be remembered, however, that although the current in the upper part of the aerial is small the voltage to earth is great, so that in a symmetrically built aerial the energy distribution at any moment will be symmetrical.



*Current Distribution.*

Fig. 323.

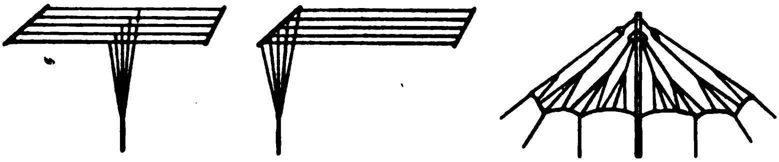
Fig. 323 (*a*) and (*b*) show the current in a vertical wire and in a roof aerial respectively, using the same conventional diagrams as before.

**569. Shore Station Aerials.**—In designing aerials for shore stations the two chief factors are—

(*a*) Permissible cost.

(*b*) Whether directional, or all round, radiation is required.

For low and medium-powered stations the most usual types are the " T " (Fig. 324 (*a*)) and the " inverted L " (Fig. 324 (*b*)). The " T " type gives the best all-round radiation.



"T" TYPE. (a)

INVERTED "L" TYPE. (b)

UMBRELLA TYPE. (c)

Fig. 324.

The " inverted L " type is markedly directional, especially if the roof portion is very long in proportion to the height of the aerial; it transmits signals more strongly in the direction opposite to that of its greatest length, and less strongly in a direction at right angles: that is to say, the horizontal portion of the aerial should be turned backwards from the direction in which the strongest effects are required either in sending or receiving.

A " T " aerial is generally supported on four or six masts, and consists of a rectangular roof of wires: the office is placed below the centre of the aerial.

The " umbrella " type of aerial, Fig. 324 (*c*), is used with portable outfits, military stations, and also at certain shore stations.

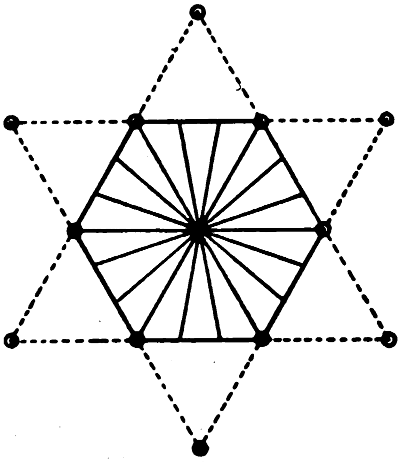


Fig. 325.

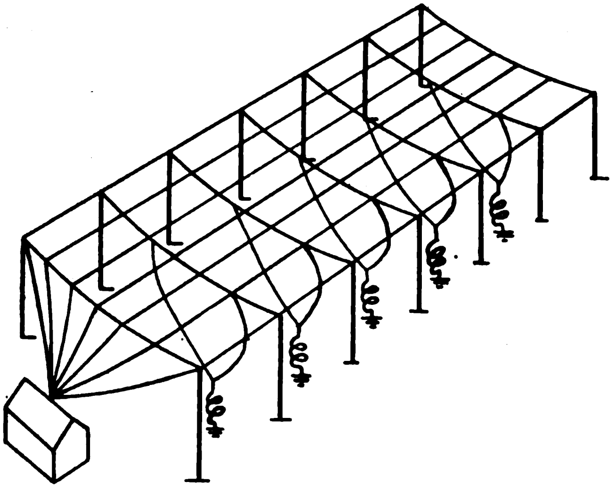
The main advantage of this type is that only one large mast is required, and that the aerial wires also serve as supporting stays. It is a poor radiator, however, as its radiation height is low for the actual height of its mast.

For high-power stations, a very convenient design is as shown in plan in Fig. 325.

This gives good all round radiation, and is readily increased at a later date by the addition of more masts, as indicated by the dotted lines, if the station is to be increased in power.

**570. The Multiple Tuned Aerial** (Fig. 326).—This is a special type of aerial fitted at certain high-power stations.

Its objects are to reduce loss resistance and to give directional transmission.



*Multiple Aerial.*

FIG. 326.

It constitutes in effect a number of separate aerials in parallel; each has its own aerial tuning coil, and is thereby independently tuned to the desired wave.

The result is that the loss resistance of the whole system is greatly reduced.

For example, the effective resistances of each of the six sections of the aerial fitted at a certain high-power station, and of the whole system, are as follows:—

| | One Section. | Whole aerial. |
|---|---|---|
| Radiation resistance | 0·07 ohms. | 0·07 ohms. |
| Tuning coil and insulation | 0·6 ,, | 0·10 ,, |
| Earth resistance | 2·0 ,, | 0·33 ,, |
| Effective resistance | 2·67 ohms. | ·50 ohms. |

Thus the efficiency of one section $= \frac{I^2R_r}{I^2R_{eff}} = \frac{0 \cdot 07}{2 \cdot 67}$ $= 2 \cdot 8$ per cent., whereas the efficiency of the whole aerial $= \frac{\cdot 07}{\cdot 50} = 14$ per cent. Now for an aerial of equal capacity and mean height arranged in the usual manner the figures for loss resistance would probably exceed those given above for one section, while the radiation resistance would remain the same, so that a great gain in efficiency is afforded by this method.

The disadvantage of the system is that it is only suitable for working on one particular wave-length, since changing wave is, obviously, a slow process.

**571. Ship Aerials.**—In ships, we find ourselves very restricted in our choice of design, owing to limitations imposed by the position of funnels, stays, guys, &c., and the necessity of arranging for several aerials.

The principal object in fitting the main aerial should be to make its radiation height as great as possible.

Small aerials should be fitted so as to be as non-inductive as possible to the main aerial, and screened from it, if possible, by a mast.

It does not matter greatly where the feeder is led into the roof portion of the aerial. It is best to feed it centrally, but, if this is not practicable, the aerial may be fed from either end.

The aerial wires are generally arranged symmetrically in the form of a cylinder or cage, held apart by circular, octagonal, hexagonal, or square spreaders.

It is customary to describe an aerial by stating first how many parallel systems of cylinders there are, and then how many wires go to each cylinder; *e.g.*, a "triple ten-fold," a "double-four-fold," &c.

The main advantage of using a number of wires in parallel, which is the usual Naval practice, is the decrease in resistance gained thereby.

**572. The Feeders.**—Every wire used in the feeder must make a good contact with the aerial wire to which it is connected. The best practice is, when possible, to make aerial and feeder wires continuous throughout.

If two feeders are used they should be arranged symmetrically with respect to large earthed objects, such as masts and funnels; otherwise their capacities will be unequal and they will take unequal currents.

## Receiving Aerials.

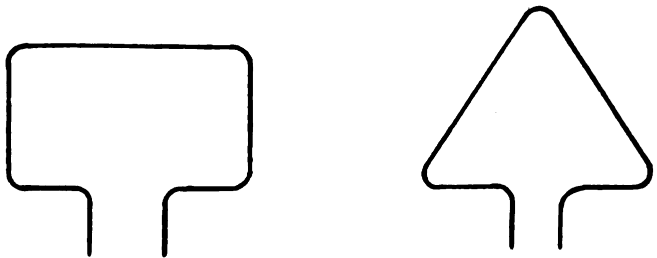
**573.** Receiving aerials may be classified under the following headings:—*Open Aerials; Loop Aerials; Frame Aerials; Ground Aerials.*

Each type meets some particular requirement; the main object to be aimed at by any type is, after providing sufficient energy to operate the receiver, to keep the signal as free as possible from interference of all sorts, whether it be undesired transmissions or atmospherics.

**574. Open Receiving Aerial.**—This is of the type we have discussed previously, but it is not necessary to aim at great height or capacity if an amplifier is included in the receiving circuit.

The important points to watch are that the insulation is good throughout, that the ohmic resistance is a minimum, and that the lead is as direct as possible. If it is led by a devious path, all sorts of undesirable capacity effects are introduced.

### 575. The Loop Aerial.



RECTANGULAR LOOP    TRIANGULAR LOOP

*Loop aerials.*

FIG. 327.

Loop aerials are used chiefly on account of their directional properties. They have a special application in direction-finding, which is discussed in the next chapter, but they are also widely used for ordinary reception.

They may be either rectangular, as in Fig. 327 (*a*), or triangular, as in Fig. 327 (*b*). The latter shape only requires one mast instead of two, but needs a greater height to give an area equivalent to that of the rectangular one.

**576. Action.**—A loop aerial will receive signals arriving from the direction in which its plane is oriented, but those coming from a direction at right angles to this will have no effect on it. Thus the loop WXYZ, shown in plan at XY in Fig. 328 (*b*), will receive maximum signals from stations at C and D, no signals from stations at A and B, and signals from E and F less than those received from C and D.

The loop WXYZ is coupled to an amplifying and detecting circuit by the mutual inductance M.

Let us consider the way in which it may be affected by waves arriving from different points of the compass, as from transmitting stations at A, B, C, D, &c., in Fig. 328 (*b*).

The effect either of the electric or magnetic field may be considered on similar lines, and in each case the result on the loop is the same.

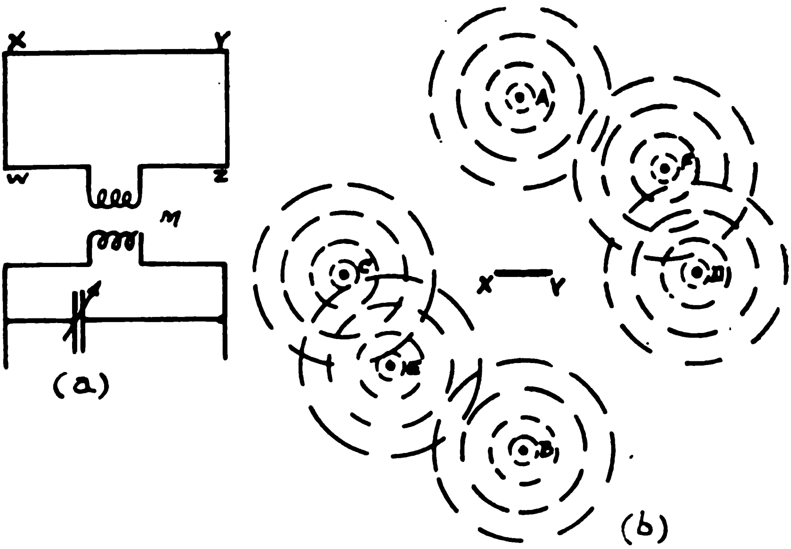


Fig. 328.

It is first desirable to make the fact clear that any alternating electric field in motion will induce alternating E.M.F.s in any vertical conductor it encounters.

In Fig. 329, P and Q are two plates of a condenser, P being 10 volts positive to Q. There is, therefore, a uniform field between them.

If we start at Q, armed with some instrument which will tell us at any instant our potential relative to Q, and move toward P,

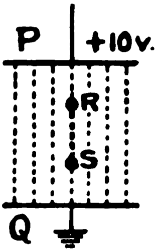


Fig. 329.

then it will be found that our potential relative to Q will increase in direct proportion to our distance from Q: in other words, we are moving up a "potential gradient."

Hence there will be a difference of potential between any two points such as R and S lying on our paths.

Again, suppose R and S are joined by a wire, then there would be a momentary difference of potential between its ends, and if those ends were joined by some external circuit unaffected by our field, a momentary current would flow.

If the potential applied to P is alternating the electric field, and current flow in any closed circuit affected by the field will be alternating also.

Equally, the plate P may be removed, and the same effects produced on a vertical conductor, by an alternating electric field arriving from some distant transmitter.

There will thus be a "voltage gradient" of so many volts (or millivolts, or microvolts) per metre in any vertical plane within the area affected by the radiation from the transmitter.

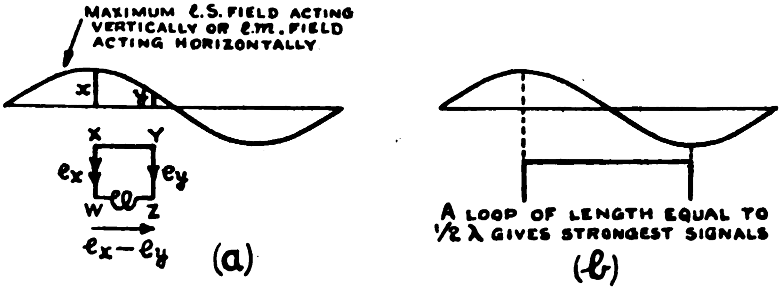

MAXIMUM E.S. FIELD ACTING VERTICALLY OR E.M. FIELD ACTING HORIZONTALLY
x
y
X
Y
$e_x$
$e_y$
W
Z
$e_x - e_y$
(a)
A LOOP OF LENGTH EQUAL TO ½ λ GIVES STRONGEST SIGNALS
(b)

Fig. 330.

Thus, if we consider the side XW of the loop WXYZ as the wave from the station at C sweeps past it, the potential of X varies sinusoidally with respect to W: so also does the potential of Y with respect to Z, but *not simultaneously*, in view of the fact that X is nearer to C than Y by the length of the loop (XY).

Consider the wave shown in Fig. 330 (*a*). At the instant shown, the E.M.F.s acting on the sides WX and YZ are both acting downwards: a voltage $e_x$ is induced in XW proportional to the ordinate $x$, and a voltage $e_y$ in YZ proportional to the ordinate $y$.

Now these two voltages $e_x$ and $e_y$ are acting in opposition *round* the circuit, so the voltage driving current through the coupling coil M is equal to their difference: *i.e.*, $e_x - e_y$.

The effect of the magnetic component of the wave may be similarly considered.

The magnetic field (by Lenz's Law) will induce an E.M.F. in any vertical conductor it encounters, and will therefore induce E.M.F.s in the two sides WX and YZ: these E.M.F.s will not be equal at the moment shown in Fig. 330, and, as before, there will be a total E.M.F. acting round the circuit equal to the difference between the E.M F.s induced in the two sides.

Further consideration (from either the electric or magnetic point of view) of the effect of any wave originated at station

C or D will show that the E.M.F. induced will be sinusoidal if the incident wave is sinusoidal, and that a maximum effect will be produced when the length X — Y is equal to half the wave-length, as in Fig. 330 (*b*); this latter condition is, however, generally impracticable, on account of considerations of space.

A wave emanating from stations A or B will strike the two wires WX and YZ simultaneously: E.M.F.s $e_x$ and $e_y$ will be generated as before, but they will be exactly equal in magnitude, and, acting in opposition round the loop, will annul one another, so that no current will flow through coil M on their account.

Arguing in the same way, it is clear that waves arriving from stations E or F will produce some effect less than that produced by stations C and D.

**577. The Polar Curve of Reception.**—We may now consider more exactly how the received currents will vary with the direction of the incident wave.

In order to do this, it will be simpler to regard the effective E.M.F. as being proportional to the total magnetic flux linkage with the loop. This method of treating a similar problem has already been used, in Chapter IV., para. **146.**

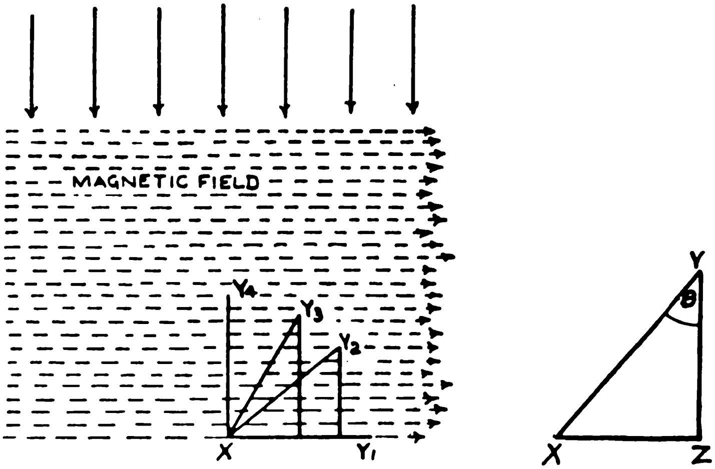


FIG. 331.

The horizontal lines in Fig. 331 represent the magnetic component of a wave travelling down the page.

Let us turn the loop XY to successive positions, as $XY_1$, $XY_2$, $XY_3$, $XY_4$.

In any position the E.M.F. induced will be dependent on the flux interlinked with the coil; therefore the E.M.F. will vary from zero in position $XY_1$ to maximum in position $XY_4$.

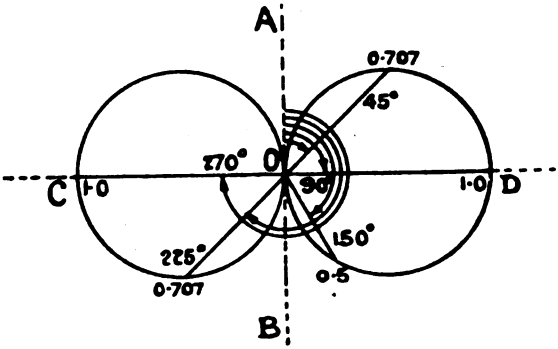
A line drawn perpendicularly from Y, as at $Y_2$, will be a measure of the flux interlinked at any moment.

Now $\frac{YZ}{XY} = \cos \theta$, where $\theta$ is the angle between the plane of the coil and the direction of the approaching wave.

Hence, if e = the E.M.F. for any position of the coil, and
$E_m$ = the maximum E.M.F. for the position $XY_4$ (when the coil is pointing to the transmitting station).

then $e = E_m \cos \theta$.

In order to indicate graphically the proportional magnitude of E.M.F. for any position of the coil, a curve may be constructed as in Fig. 332 by laying off from a centre O the angles through 360°, and the corresponding values of the cosines of the angles (from the table of cosines, page **534**) to any convenient scale; *e.g.* cos 45° = 0.707; cos 90° = 1; cos 150° = cos 30° = 0·5; cos 225° = cos 45° = ·707; cos 270° = cos 90° = 1; &c.



*Polar Reception Curve of Loop or Frame Aerial.*

FIG. 332.

The diagram constructed in this manner will be found to take the form shown, of two circles touching at the point O.

It is termed a "Polar Curve," and is a plot of the equation given above.

This Polar Curve indicates the proportional strength of current received from a fixed station by a loop aerial which is revolved through 360°, or alternatively of the current received in a fixed loop by (say) a ship steaming round the loop in a circle, and transmitting continuously.

The line COD, indicates the direction of the transmitting station, and the line AOB, the direction of zero signals.

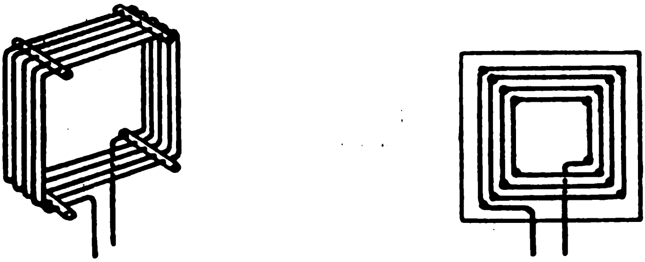
Similarly the polar curve of an open aerial would be represented by a circle drawn with O as centre, indicating equal receptivity from all directions.

The principles of the loop aerial have now been discussed sufficiently for the purpose of this chapter, where we are only concerned with the loop as used for a receiving aerial. In the next chapter its use for direction-finding purposes will be further discussed.

**578. The Frame Aerial.**—The flux linkage with a loop will depend on

(*a*) the strength of the magnetic field.
(*b*) the area of the loop.

When the permissible area limit of such a loop is reached, signal strength may be increased by using more than one turn of wire, as in Fig. 333, which shows (*a*) Box form, and (*b*) Pancake form, of a Frame Aerial.



BOX FORM (a)

PANCAKE FORM (b)

*Frame Coil Aerials.*

FIG. 333.

**579. Application.**—Loop and frame coil aerials may be used in ordinary reception work for three purposes :—

(*a*) to facilitate duplex working.
(*b*) to cut out interference from other stations.
(*c*) to decrease atmospheric interference.

(*a*) Duplex working means that a station operating a point-to-point service with another station, is able to transmit and receive simultaneously, using different wave-lengths for transmission and reception.

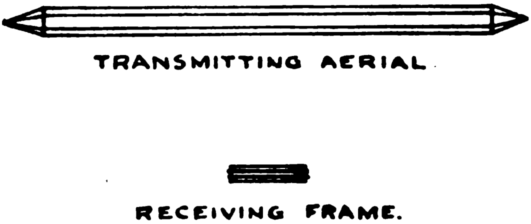


FIG. 334.

To effect this, reception is carried out on a loop aerial placed with its plane at right angles to the direction of the transmitting aerial, as in Fig. 334.

It should then be unaffected by the latter, and if the two aerials are pointing at the distant station, as they should be, it will be in the best position for receiving the desired signals.

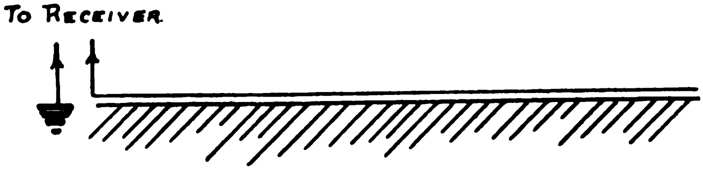
(*b*) If interference is experienced from one or more stations which do not lie in the same direction as that of the station from which it is required to receive signals, reception will be considerably improved by the use of a loop aerial suitably oriented.

(*c*) In certain parts of the world, the majority of the atmospherics experienced are markedly directional. In such a case, if all-round reception is not required, the use of a loop or frame aerial may decrease atmospheric interference considerably.

Moreover, even atmospherics which are not directional appear to affect a loop aerial less severely than an open one.

**580. Ground Aerial.**—This denotes a type of aerial used solely to mitigate atmospheric interference.

It simply consists of an insulated wire laid along the ground, as in Fig. 335.



*Ground Aerials.*
FIG. 335.

Connections are made from the receiving instruments to the wire and to earth. The free end of the wire is left insulated, and the wire is laid out in the direction from which reception is desired.

The wire constitutes the aerial, and the thickness of the insulating covering, which separates the wire from earth, together with the length of wire, determine the aerial capacity.

Such an aerial is found, under certain conditions, to increase the ratio of signal to atmospheric interference, and may therefore prove advantageous.

Insulation difficulties may be minimised by running the wire along the centre of a drain pipe, either on or below the surface of the ground.

## Earth Systems.

**581.** An earth system is an essential component of an open aerial system, whether used for transmission or reception, being required as the connection to the lower plate of the condenser, whose upper plate is formed by the aerial.

Earth systems are of two classes, viz. (*a*) the Conductive Earth and (*b*) the Earth Screen.

**582. The Conductive Earth in Shore Stations.**—The system that has been in use for a great number of years is a good low-resistance connection to the surface of the earth by means of buried metallic wires and plates.

A large number of wires are buried about a foot deep over an area rather greater than that covered by the aerial, and may be connected at their ends nearest to the W/T Station, to a number of copper or zinc plates.

The connections from the wireless plant to the earth system must have good current-carrying capacity, since current density is greatest in the earth lead, and further, the insulation of these connections is important.

It is very bad practice to lay wires loosely along the ground from the station.

They should be carried on insulated supports to the point where connection to the buried earth system is required. Otherwise, a large proportion of current would leave the earth-feeder wires at the point where they first touched the ground, and as this would give a high resistance contact, heavy losses would occur.

As with the wires composing the aerial, so also with those composing the earth; their arrangement should be symmetrical about the station both as regards length and disposition, for any lack of symmetry will result in those wires which are of least inductance carrying more than their share of current, an ohmic loss of energy being thus introduced.

**583. The Multiple Earth.**—A good example of the importance of this principle is furnished by the "multiple earth" fitted at the Ste. Assise Station in France.

The system consists of a network of copper wires spaced 10 metres apart, divided into sections each of which carries approximately the same number of lines of force.

Current between these sections and the transmitting plant is conveyed by overhead wires, and in order to ensure that the impedances of these paths are equal, artificial inductances and condensers are inserted in them. No attempt at a perfect balance is made, however, as this would make the adjustment too critical for variations of wave-length.

As a result, the total effective resistance of the aerial system is brought down to the very low figure of 0·54 ohms, as compared to 1·9 ohms which was the resistance before the multiple earth was adopted. This figure is made up as follows :—

| | | |
|---|---|---|
| Radiation resistance - - - - | 0·19 | ohms. |
| Resistance of inductances - - - | 0·1 | ,, |
| ,, aerial wires - - - | 0·05 | ,, |
| ,, earthing system - - - | 0·2 | ,, |
| | 0·54 | ,, |

This corresponds to an aerial efficiency of 0·19/0·54 × 100 = 35 per cent.

**584. The Earth Screen.**—The earth screen, Fig. 336, as fitted in many shore stations resembles the Lodge-Muirhead "balanced capacity."

In its earlier application, however, the lower wire network was generally considered to act merely as a capacity to earth, and its true function as an earth screen was not realised.

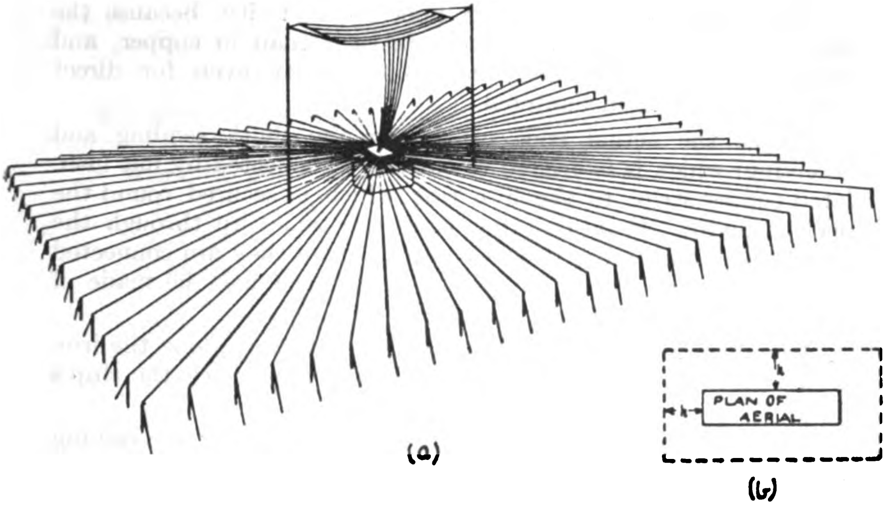


Fig. 336.

The function of the screen is to intercept the lines of force from the aerial to earth and to carry the return current on the screen wires rather than by the earth.

Further, when the earth system is placed on or in the earth, heavy eddy current losses occur in the earth, owing to its poor conductivity.

When the earth system is raised up, as in the " earth screen," these losses are reduced.

The earth screen should extend on all sides beyond the area covered by a plan view of the aerial system by a distance equal to the height of the aerial.

The wires composing it should not be spaced closer than a distance three times the height of the screen above the ground.

At certain Naval Stations good results have been achieved by earthing the outer edges of the earth screen.

**585. The Conductive Earth in Ships.**—A ship's earth is usually very good compared with that of the average shore station.

In view, however, of the property of high frequency currents of flowing only on the surface of conductors, the precaution must be taken of providing a direct path of good conductivity for the earth currents.

It might be assumed that it would be good enough to tuck the end of the earth connection under a bolt in the side of the wireless office, and that then the currents would flow straight through the hull to earth.

They would not do anything so simple, however, but would take a path up inside the nearest bulkheads to the upper deck—across the deck and so down the outside of the hull, *i.e.*, always "on the surface."

This path would be one of poor conductivity, because the skin effect in iron is much more marked than in copper, and riveted joints which have poor conductivity even for direct current, would be encountered.

Hence the actual ends of the circuits (both sending and receiving) which it is desired to earth are connected by flat insulated copper strips to the iron ring which is secured round the deck insulator. From this ring wires are taken up through the aerial trunk to the top deck insulator, where they are connected to another ring. Alternatively the trunk itself may be made of copper and used as the earth lead.

From the top insulator the earth currents flow along the iron deck underneath the teak planking before they reach the ship's side.

It must be remembered that the earth connection for receiving sets must be made quite as carefully as that for transmitting sets, as one cannot afford to lose any of the small amount of power available in received signals.

## Interference.

**586.** This is a convenient point to discuss the general problem of interference, and to explain some of the terms used in this connection.

The problem of minimising interference is the most serious one affecting the wireless engineer at the present day.

A position which may be termed "wireless saturation" is rapidly being approached; it is becoming increasingly difficult to fit in any new W/T service in Europe between medium-power stations on account of congestion of wave-lengths, while in the band of long wave-lengths (8,000 to 30,000 metres) used by long range stations, very few more services are possible in the whole world.

In these circumstances every endeavour must be made to decrease interference, and international agreements must be framed to the same end.

There seem to be four lines of attack—

(*a*) The total abolition of spark transmission.
(*b*) The use of very sharply tuned transmitters only, in conjunction with highly selective receiving circuits.
(*c*) The use of note selectors, as in para. **501.**
(*d*) The use of directional transmitters (*see* Chapter XVII, para. **614**).
(*e*) The extended use of waves below 100 metres.

Wireless interference may be classified under headings as follows :—

(*a*) Shock interference.
(*b*) Tuned interference from—
  (i) the transmitted wave;
  (ii) harmonics of the transmitted wave.

**587. Shock Interference.**—The evil effects of this have been referred to in Chapter IX.

It arises from—

(*a*) atmospherics;

(*b*) tightly coupled and quenched spark transmitters, or any other wireless system emitting a heavily damped wave;

(*c*) power lines, tape machine lines, tram circuits, commutator sparking, &c., in the immediate vicinity of the receiving station.

The heavily damped impulse strikes the receiving aerial, and if of sufficient amplitude, sets the receiving circuits in oscillation at the frequency to which they are tuned, irrespective of the frequency of the incident wave.

The effect is similar to that produced by striking a bell with a hammer.

It cannot be said that there is at present any practical method of cutting out this interference without unduly weakening the required signal; it can only be mitigated by the use either of special forms of aerial (as previously described), or of limiting devices, and note selectors, in the receiving circuit.

**588.** Before going on to discuss tuned interference as produced by various types of emission, it is necessary to explain the terms "frequency breadth," "spread over," "equivalent decrement," and "side bands," which are frequently used in discussions on the interference problem.

The terms "frequency breadth" and "spread-over" are synonymous. They refer to the degree of interference caused by a particular emission on the frequencies immediately above and below it.

Thus one might find that a certain signal of strength 8 on 1,000 metres (300 kc.), was strength 6 when the receiving gear was set to 315 or 285 kc.

One would then say that the wave had a frequency breadth of 30 kc. at 6/8ths of the fundamental signal strength.

The frequency breadth of a wave determines the interference it produces, whether such breadth is due to modulation, high signalling speed, spacing wave, actual decrement, harmonics, variation of transmitter frequency, &c.

The meaning of this statement will become clearer after the next few paragraphs.

**589. Equivalent Decrement.**—In Chapter VII, para. **327,** reference was made to the decrement of a spark circuit. It was explained there that the decrement of a circuit controlled the rate at which any free oscillation set up in it would die away.

It would seem then that in C.W. transmission we were not interested in decrements, but this is not so; whenever a continuous wave is keyed or modulated the decrement of the circuit becomes of importance, as it affects the frequency breadth of the wave emitted.

The decrement of a circuit of effective resistance R ohms, tuned by means of inductance L (henries) to a frequency $f_r$

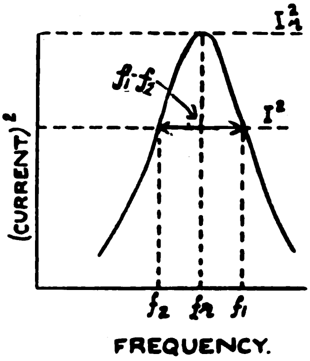
$$= \delta = \frac{R}{2\,f_r\,L} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

(which simplifies into the form

$$\delta = \frac{R}{9{\cdot}6}\sqrt{\frac{C}{L}}$$

when units of mics. and jars are used).

If we take measurements either on a wavemeter or on a receiving set fitted with some hot wire recording instrument, we shall get a curve as in Fig. 337.



*Resonance Curve.*

**Fig. 337.**

Here we have a plot of the readings of the hot wire instrument (which are proportional to the square of the current in the measuring circuit) against various frequencies.

The decrement of the two circuits combined, *viz.*, of the transmitting circuit and of the measuring circuit, is then given by the formula

$$\delta = \pi\frac{f_1 - f_2}{f_r}\sqrt{\frac{I^2}{I_r^2 - I^2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where $f_1$ and $f_2$ are the frequencies below and above the resonant frequency $f_r$, at which an equal current I is obtained. $I_r$ is the current at the resonant frequency $f_r$.

It is most convenient to read $f_1$ and $f_2$ at points where $I^2 = \frac{1}{2} I_r^2$: the expression $\sqrt{\frac{I^2}{I_r^2 - I^2}}$ then $=1$, and the equation becomes

$$\delta = \pi\frac{f_1 - f_2}{f_r} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The decrement of any circuit can be determined by taking measurements in this manner, and then deducting the decrement of the measuring circuit.

Further, we may combine equations (1) and (3) thus :—

$$\frac{R}{2f_r L} = \frac{\pi(f_1 - f_2)}{f_r} \text{ or}$$

$$\frac{R}{L} = 2\pi(f_1 - f_2) \text{ ..........................(4)}$$

Thus in any transmitting circuit, the greater the ratio of $\frac{R}{L}$ the greater the equivalent decrement and frequency breadth of the transmitted wave, and in any receiving circuit the greater the ratio of $\frac{R}{L}$ the less selective will it be.

Hence a circuit with a given decrement $\delta$ will emit waves with a ratio of frequency breadth $(f_1 - f_2)$ to resonant frequency $(f_r)$ as given by equation (3).

Conversely we may say of any particular wave form having a certain frequency breadth that it has also a certain **equivalent decrement** as measured above.

It does not matter whether the wave is spark, keyed C.W., I.C.W., or R/T: an equivalent decrement can be deduced by measurement in all cases.

**590. Sidebands.**—The term "sideband" has been introduced in the development of R/T. Its meaning is slightly different from that of "frequency breadth," and it is strictly admissible only when the modulation is periodic.

A tonic train wave may be analysed into three components, *viz.*, the carrier frequency, the carrier frequency + the modulating frequency, and the carrier frequency − the modulating frequency.

For example, a tonic train transmission on (say) 100 kc. (3,000 metres) modulated at 500 cycles per second, will have sidebands of $100 - 0{\cdot}5 = 99{\cdot}5$ kc. and $100 + 0{\cdot}5 = 100{\cdot}5$ kc.

In **radio telephony** a large number of speech sounds are periodic for a sufficiently large number of cycles for the modulated wave to have in the main the properties of tonic train. The modulating frequencies are continually changing, however, with the different sounds, and so the sidebands are said to extend both above and below the carrier frequency, by an amount depending on the frequency breadth of the modulation applied (*see* para. **541**).

**591. Tuned Interference.**—The waves in use for wireless communication are classified by International agreement under the following headings :—

*Type A. Continuous Waves.*—Waves which, after reaching the steady state, are periodic; *i.e.*, the successive oscillations are identical.

*Type A1. Continuous Waves, unmodulated, key controlled.*—Continuous waves of which the amplitude or frequency is varied by the operation of keying in telegraphic transmission (*i.e.*, ordinary C.W.).

*Type A2. Continuous waves modulated at audible frequency.*—Continuous waves in which the amplitude or frequency is varied in a periodic manner at an audible frequency (*i.e.*, I.C.W., including tonic train and chopped C.W.).

*Type A3. Continuous waves modulated by speech.*—Continuous waves in which the amplitude or frequency is varied according to the characteristic vibrations of speech (*i.e.*, R/T.).

*Type B.*—Damped waves. Waves consisting of successive wave trains in which the amplitude of the oscillations, after reaching its maximum, declines gradually (*i.e.*, spark).

Of the above, **Type A** cannot be used for signalling, on account of the necessity of modulating the emission in some way in order to communicate.

**Type A1** is the nearest approach to the ideal as regards sharpness of tuning, but even it does not consist of an absolutely single frequency, by reason of its variations in amplitude under the operation of keying.

When a W/T transmitter circuit is being interrupted by a signalling key the oscillation takes time to die away when the key is released and time to grow again when the key is pressed.

The rate of decay and growth depends on the logarithmic decrement of the circuit. Thus, while the current is growing and dying away it will not stay constant at a single frequency, but will spread out to a certain extent dependent on the decrement.

Further, at really high keying speeds the current never rises to a steady value, and the keying may be looked on as a modulation applied to the continuous wave : thus Type A1 keyed at high speed may have as great a frequency breadth as Type A2, or greater.

The decrement of a set designed for receiving high speed signals is a matter for careful consideration. On the one hand, the greater its decrement, the less selective and the less sensitive will it be. On the other hand, if its decrement is very low, current resulting from an applied E.M.F. takes some time to build up and die away, and this will result in the dots of the Morse code signals being of much lower amplitude than the dashes, which is undesirable, especially if the signals are recorded by some automatic relay which requires a certain minimum current value to operate it.

These considerations also apply to a circuit intended for the reception of radio-telephony (para. **541**).

The interference due to **Type A3** (R/T) is largely due to the sidebands resulting from modulation, as explained previously (*see* para. **541**).

The frequency breadth due to **Type B** (spark waves) is chiefly due to the two component waves dependent on the coupling between primary and aerial circuits (*see* para. **320**).

Take a 600 metre wave transmitted from a circuit where a 20 per cent. coupling is being used. For 20 per cent. coupling, $k$ (the coupling factor) $= 0 \cdot 2$.

The two component waves are

$$\lambda_1 = \lambda\sqrt{1-k} = 600\sqrt{0\cdot 8} = 536\cdot 7 \text{ metres, and}$$
$$\lambda_2 = \lambda\sqrt{1-k} = 600\sqrt{1\cdot 2} = 657\cdot 3 \text{ metres.}$$

Thus two peaks of interference occur at these two wave-lengths, and serious jamming will occur over a still wider range.

For this reason the use of spark may be abolished by international agreement.

**592. Harmonic Interference.**—It has been explained previously that a harmonic is simply a sub-multiple of wave-length or a multiple of frequency.

Now, it can be shown mathematically that, within certain limits, it is possible to represent any kind of wave form by means of a summation series of sines, *i.e.*,

$$A \sin \omega t + B \sin 2\omega t + C \sin 3\,\omega t + \ldots\ldots, \text{ \&c.}$$

Where A is the current amplitude of the fundamental frequency, B of the 2nd harmonic, C of the third, and so on (para. **530**).

The above expression indicates that any wave form is made up of a number of sine curves of different amplitude, each being a definite multiple of the fundamental frequency.

A wave which is a true sine curve will be represented by the A sin $\omega t$ term only ; as a rule, however, certain harmonics are present in all transmission, though they may not necessarily be of sufficient amplitude to cause serious interference.

Thus the harmonics of a wave of 6,000 metres are as follows :—

$$\text{Fundamental} = 6{,}000 \text{ metres.}$$
$$\text{2nd harmonic} = \frac{6{,}000}{2} = 3{,}000 \text{ metres.}$$
$$\text{3rd harmonic} = \frac{6{,}000}{3} = 2{,}000 \text{ metres.}$$
$$\text{20th harmonic} = \frac{6{,}000}{20} = 300 \text{ metres, \&c.}$$

Harmonics are more noticeable in transmissions from C.W. stations. In I.C.W., R/T. and spark transmissions they have less time for building up, and so have a less severe effect.

Harmonics may be caused by

(*a*) Subsidiary aerial oscillations caused by the transmitting set, and

(*b*) Distributed capacity and inductance in the aerial circuit.

**593.** The more the voltage applied to the oscillatory circuit departs from a pure sine curve, the greater the energy emitted in the form of harmonics.

The arc, for example, is continually being extinguished and restruck, and is not absolutely uniform in its behaviour from cycle to cycle.

The variation in voltage across it which is applied to the oscillatory circuit cannot therefore be sinusoidal, but must approximate to a series of shocks.

A high power arc, connected directly in series with an aerial, is found in practice to generate "mush" and harmonics which run as far down as the twentieth before they become negligible.

(The term "mush" is exactly expressive of the effect it describes: it denotes a general rushing, noisy disturbance, flatly tuned, on the more important harmonics, and is most difficult to eliminate).

Similarly, a valve set directly coupled to the aerial and operating with a considerable negative voltage on the grid, does not energise the aerial sinusoidally (as was pointed out in para. **513**).

In both cases harmonic emission may be considerably reduced by the use of independent drive, coupled circuits and similar devices, but at the expense of efficiency in generation of oscillations on the fundamental wave-length.

**594.** Harmonics which have nothing to do with transmission may be introduced in the adjustment of the receiving apparatus.

For example: suppose the aerial and other portions of a receiving circuit are tuned to resonance with a continuous wave of 6,000 metres: it will then be found that signals can be received if the heterodyne circuit is set to approximately 3,000 or 2,000 metres, though less strongly than if the correct setting is employed.

This effect is due to the interaction of the incoming and heterodyne currents and has nothing to do with the form of either of the two waves.

## CHAPTER XVII.

# DIRECTIONAL RECEPTION AND TRANSMISSION.

## Direction-finding (D/F).

**595.** We will now discuss the various methods employed for obtaining the direction and position of a transmitting station, by the use of the properties of loop aerials.

There is not space available here for a full description of the technique of direction-finding; reference should be made to some standard text-book on the subject.*

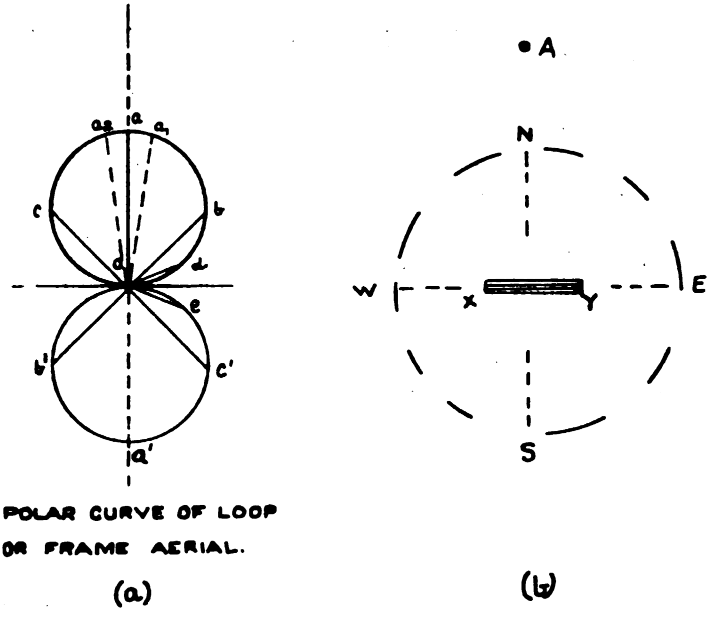
The most common application of D/F is in determining the position of a ship at sea, or of an aeroplane in flight.

The apparatus used in D/F falls under one of three headings :—

(*a*) The rotating frame coil.
(*b*) The Robinson system.
(*c*) The Bellini-Tosi system.

**596. The Rotating Frame Coil.**—This consists simply of a multi-turn coil of small dimensions, so mounted that it can be swung round by hand in any required direction. It carries a pointer which indicates the bearing in which the plane of the coil is directed, relatively to the North.

It was shown in the last chapter, para. **577**, that the polar curve of reception of such a coil is as shown in Fig. 338(*a*).



(a) (b)

Fig. 338.

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* *See* R. Keen, "Direction and Position Finding by Wireless," and Service handbooks.

Let us examine carefully exactly what is meant by this statement.

Suppose we have a rotatable loop as at XY, and a transmitting station as at A, due north of the loop. When the loop is pointing East or West, no current is induced in the loop and no signals are heard.

When the loop is pointing North or South, maximum signals are heard, as indicated by the length of the lines Oa or Oa′.

When the loop is pointing N.E. or S.W., signals will be heard, less than the maximum, in the proportion that the lines Ob or Ob′ bear to the lines Oa or Oa′.

Similarly, when the loop is pointing N.W. or S.E., signals will be heard with a strength proportional to the lines Oc or Oc′.

It will be noticed that the loop cannot discriminate as to the *sense* of a bearing; that is, when it points due north, there is no indication whether the transmitting station is lying due north or due south. To effect this, the use of a sense-finder (*see* para. **606**) is necessary.

It should also be noticed that when the frame is swung from a position corresponding to Ob to one corresponding to Oc′, the phase of the current changes by 180°; *i.e.*, when the coil is pointing N.E., the edge Y is nearer to the transmitter, and a positive half cycle of the incident wave will drive current round the coil in (say) a clockwise direction; when the coil is pointing S.E., the edge X is nearer to the transmitter, and the direction of current will be reversed for a similar positive half cycle.

Thus when an alternating E.M.F. is being induced in a frame aerial by an incident wave, the phase of the E.M.F. will be shifted through 180° as the frame is rotated through the position of zero linkage.

**597. Method of taking a Bearing.**—A bearing is obtained by comparing the strength of received signals for various positions of the coil.

If the coil is swung from a position as at $Oa_1$, to a position as at $Oa_2$, the change in signal strength would be so small as to be imperceptible.

It is, therefore, more convenient to swing on either side of zero signals. Thus, if the frame is swung between positions corresponding to Od and Oe, the signal strength will vary from (say) strength 6 down to zero, and up to strength 6 again.

The operator notes that he gets the same strength of signals when his pointer is at 75° and 105°; adds these together and takes the mean $\left(\frac{75^\circ + 105^\circ}{2} = 90^\circ\right)$; then deducts 90° to allow for the fact that he is working on the zero, instead of the maximum position: hence the required bearing = 0° = North.

More conveniently, the pointer may be set back by 90° to eliminate the last operation, and give the correct bearings directly.

The operator would get precisely the same results when the coil was turned through 180°; *i.e.*, at 75° + 180° = 255° and 105° + 180° = 285°, and would be in doubt whether the transmitting station were north or south of him.

**598. Disadvantages of the Frame Coil.**—The rotating coil system has many points in its favour, but suffers from the following defects—

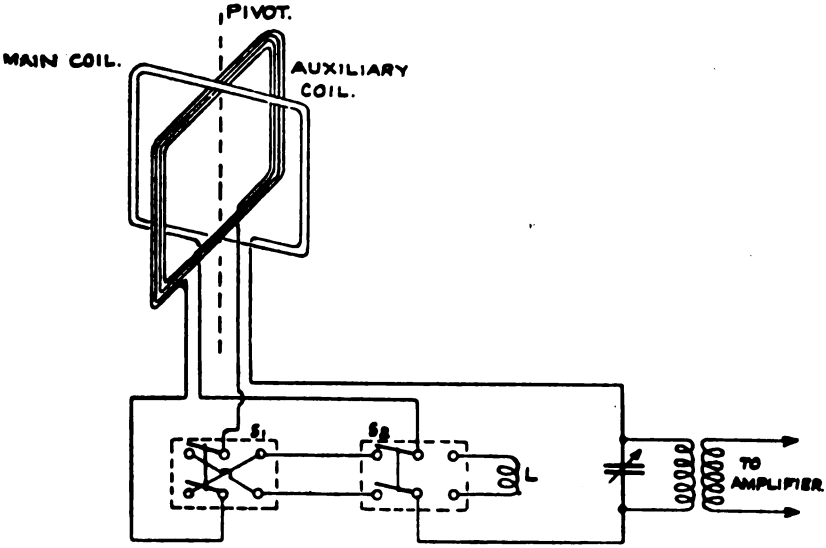
(*a*) It is difficult to take rapid " snap " bearings owing to the weight of the frame.

(*b*) If a very small frame is used, high amplification is necessary, with numerous attendant difficulties.

(*c*) It is difficult to compensate the frame for the effect of large metal bodies nearby, such as gun turrets, funnels, &c.

**599. The Robinson system** enables signals to be heard the whole time that bearings are being taken, and obviates the necessity of swinging the frame rapidly in order to take a bearing.

The method consists essentially in the use of two frame aerials (Fig. 339) fixed at right angles to one another, the system being free to rotate in a vertical plane.



*Robinson D/F Circuit (Diagrammatic).*
Fig. 339.

The two coils are known respectively as the Main Coil and the Auxiliary Coil; the auxiliary coil has approximately 2½ times as many turns as the main coil.

The two coils are connected in series with one another, but the direction in which the auxiliary coil is connected may be reversed by the switch $S_1$. The switch $S_2$ is used to cut the auxiliary coil out of circuit, and to replace it by a coil L of equal inductance.

If now the main coil is directed exactly on the transmitting station, no E.M.F. will be induced in the auxiliary coil.

If, however, as is probable, the main coil is a little off the bearing, a small E.M.F. will be induced in the auxiliary coil, as indicated by the ordinate Od in Fig. 338.

Let us assume that with switch $S_1$ to the left, the E.M.F.s due to the main and auxiliary coils are acting in the same direction round the circuit.

Now throw the switch $S_1$ over to the right; the E.M.F. due to the auxiliary coil will now be in opposition to that due to the main coil, and signals will be reduced in strength.

If therefore the switch is rapidly reversed, signals will vary in strength, until the main coil has been swung to the true bearing of the transmitting station, when reversals of the switch will have no effect on the strength of signals.

This system obviates the disadvantage (*a*) mentioned in para. **598,** and has the great advantage that signals can be read continuously while the bearing is being taken. It is used extensively in the Royal Air Force, but not in H.M. Navy, for the reason that it is still open to disadvantages (*b*) and (*c*) above.

**600. The Bellini-Tosi system** is the one that has been adopted as standard in H.M. Navy.

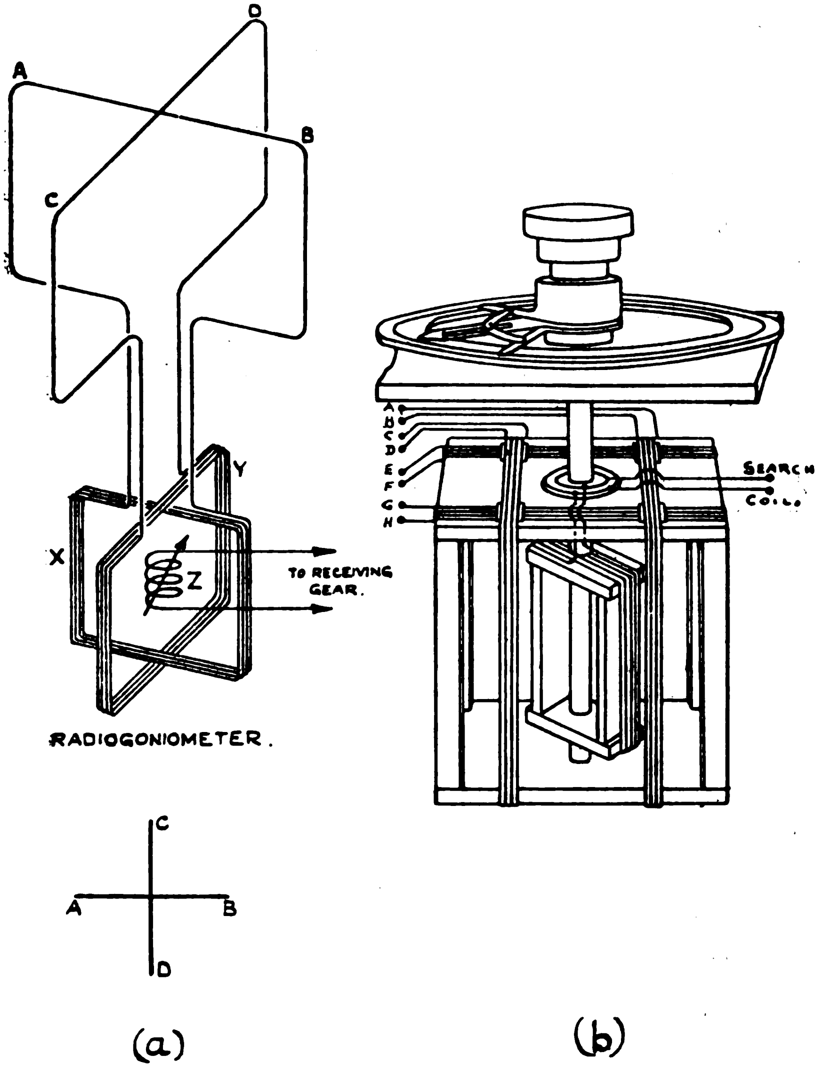
The system consists of two single-turn loop aerials AB and CD (Fig. 340 (*a*)) fixed rigidly at right angles to one another, and connected to an instrument termed a Radio-Goniometer.

The Radio-Goniometer (Fig. 340 (*b*)) comprises two fixed coils—each split into two halves—at right angles to one another, and a third coil—termed the "Search Coil"—mounted so that it can be rotated freely round a vertical axis, and connected to the receiving gear.

Now, consider what is the effect of a wireless signal incident on this system. Suppose, first, that the signal is arriving in the plane of the loop AB (Fig. 340 (*a*)); in this case no current will be induced in the loop CD because it is at right angles to the direction in which the waves are travelling, whereas the loop AB will be in its position of maximum receptivity and will have a current induced in it. This current will produce a magnetic field along the cylindrical axis of the field coil X.

On the other hand, in the case of a wave which is incident exactly in the plane of the loop CD, a magnetic field will be produced only along the axis of the field coil Y.

If, however, the direction from which the wave is arriving lies somewhere between the planes of the two loops, both loops, and hence both field coils, will have currents induced in them, and in the neighbourhood of the search coil there will now be two magnetic fields at right angles to each other, the relative strengths of which will depend upon which loop most closely coincides in direction with that of the incident wave. The two magnetic fields produce in the radio-goniometer a resultant field which bears exactly the same space relationship to the planes of the field coils as the direction of the received signal does to the planes of the loops.



(a) (b)

FIG. 340.

The exact direction of this resulting field is determined by means of the search coil Z.

The E.M.F. induced in the winding of the search coil is proportional to its linkage with the magnetic field, and consequently as the search coil is rotated inside the field coils, there will be a maximum E.M.F. when the cylindrical axis of the winding lies along the direction of the resultant field, and zero E.M.F. when its axis is at right angles to the resultant field.

As the search coil is moved round, therefore, the signals in the telephone receivers are found to indicate alternate maximum and minimum signals 90° apart, just as in the case of the rotating frame aerial.

A pointer is attached to the spindle of the coil and a scale is fixed to the frame of the instrument so that the direction of the field, and thus the direction of the incident wave relative to the aerials, can be read off.

The true bearing of the wave may be determined (*a*) in the case of a shore D/F station by so placing the goniometer scale that its zero position corresponds with true north, (*b*) in the case of a ship D/F station by providing a " gyro repeater "—*i.e.*, an instrument connected to the master gyro compass—close to the radiogoniometer, and setting the zero of the goniometer scale in the fore and aft line of the ship.

A still better arrangement is that the scale of the goniometer should be rotated by the gyro compass transmitter, thus eliminating one operation.

**601. Advantages of the Bellini-Tosi System.**—It will be observed that the Bellini-Tosi system is equivalent to the rotating loop aerial.

Its advantages for ship use are as follows :—

(*a*) it is the only type employing an aerial system comparable in size with the metal structures which are found in ships ;

(*b*) it has no heavy structure to rotate ;

(*c*) its circuit can provide for automatic correction of errors due to the ship.

**602. Conditions for Accurate Working.**—In order that accurate bearings may be obtained, the following conditions must be fulfilled :—

(*a*) The radio-frequency currents in the two aerials must be in phase. If this condition does not prevail, a rotating field is produced which is superimposed on the normal stationary field, giving impure (or " woolly ") minima.

(*b*) The aerials must be approximately of equal resistance to radio-frequency currents, otherwise—

(i) the currents which flow as a result of the signal E.M.F. will not be of the correct proportional amplitude ; and

(ii) in the case of spark signals, the damping of the aerials will be unequal, again giving bad minima.

(*c*) The aerials with their associated circuits must possess equal receptivity ; aerials unequal in this respect give displaced minima.

(*d*) There must be no mutual inductance or capacity between the aerial circuits, nor between the primary windings of the goniometer and the amplifier or tuned circuits.

(*e*) The windings of the goniometer field coils must be of equal resistance, have the same number of turns, be of the same size, and be symmetrically disposed with regard to the search coil.

(*f*) The receiving instruments must be so effectively screened that there is no direct induction into their circuits by the incoming waves.

**603. The Bellini-Tosi Circuit.**—The loops used in H.M. Ships usually consist of one rectangular one between the funnels, or between the forward funnel and the foremast, and one triangular one rigged athwartships (Fig. 341).

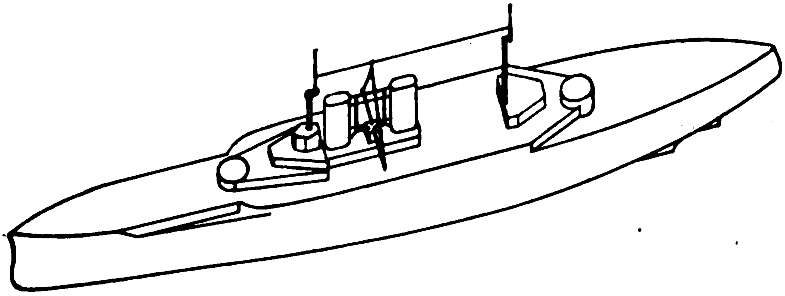


Fig. 341.

The beam loop is always larger in area than the fore-and-aft loop for the following reason:—

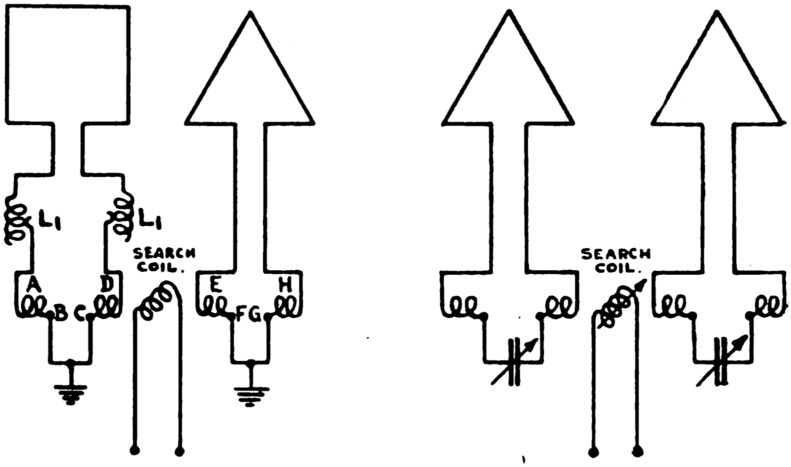
The advancing wave, in addition to inducing E.M.F.s in the loops, will also induce them in the structure of the ship itself, and the resulting currents in the structure will set up a magnetic field the effect of which is bound to be felt on the loops.

The fore-and-aft component of this magnetic field, by reason of the shape of any vessel, is bound to be much stronger than the athwartship component. Hence, when considering the combined effects on the loops of the field of the advancing wave, and of that due to currents in the ship's structure, it is clear that the apparent direction of the transmitting station will be drawn towards the fore-and-aft line. The amount of the error will vary with the relative bearing of the transmitting station; on the beam and right ahead and astern the distortion is nil, and on the bow and quarter a maximum.

Since, as indicated above, the distortion is "**quadrantal**"—*i.e.*, always towards the fore-and-aft line and tending to exaggerate the current strength in the fore-and-aft loop—it can be corrected by decreasing the area of the fore-and-aft loop till the distortion on the bow and quarter is nil.

**604.** The coils of the goniometer are each split into two halves, terminals from which are placed on the outside of the box.

Typical circuit arrangements are illustrated in Fig. 342.



(a) UNTUNED AERIALS. (b) TUNED AERIALS.

*Bellini-Tosi Circuits.*

FIG. 342.

The inductances $L_1$ are provided as a method of finally balancing the two aerials after the area of the two loops has been adjusted as nearly as possible to eliminate quadrantal error; they are shown joined in series with the fore-and-aft loop on the assumption that the area of this loop is slightly too great.

**605. Tuned versus Untuned Aerials.**—Each loop may either be tuned to resonance by means of condensers joined in series between the two halves of each field coil (Fig. 342 (*b*)) or the inner ends of the field coils may be connected to earth (Fig. 342 (*a*)).

The former condition is naturally the more sensitive, but is not widely used on account of the difficulty of obtaining an accurate balance between the two aerials.

If one aerial is the least bit out of tune, conditions (*a*) and (*c*), para. **602**, will not be met.

In shore stations the aerials can be made of exactly similar dimensions, but then the difficulty arises of changing waves quickly; the tuning must be so exact that the operation of changing wave is a slow one, and shore stations working on tuned aerials are confined to working on one wave.

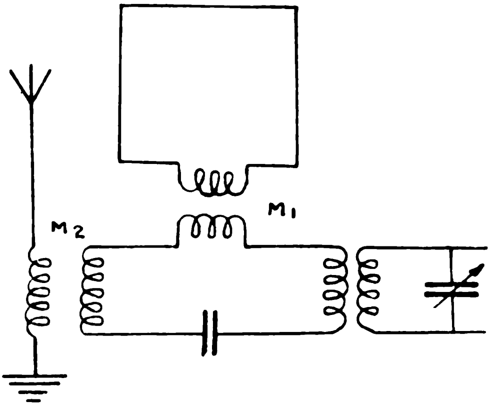
In ships the difficulty of balancing the aerials rules out the use of tuned aerials.

The inductances $L_1$ could not be used, since these would upset the tuning as well as the balance.

Resistance could be used, but the amount required would vary for each wave-length.

Hence the usual practice is to use untuned aerials and compensate for lack of sensitivity by additional amplification.

**606. Determination of Sense.**—It is often of great advantage to be able to determine the " sense " of a signal; *i.e.*, to determine the absolute direction from which it comes, and not be left in doubt whether it comes from (say) north *or* south.



*Circuits to explain Sense-finding.*

FIG. 343.

Suppose we have an open aerial and a closed loop coupled to a common circuit, as in Fig. 343. Let us assume that the plane of the loop is oriented in an east-west direction, and that, by reason of the direction of the couplings $M_1$ and $M_2$, a signal coming from the west will cause a current due to induction from the loop to flow in the intermediate circuit in the same direction as a current due to induction from the open aerial, for any given half cycle of the applied E.M.F.

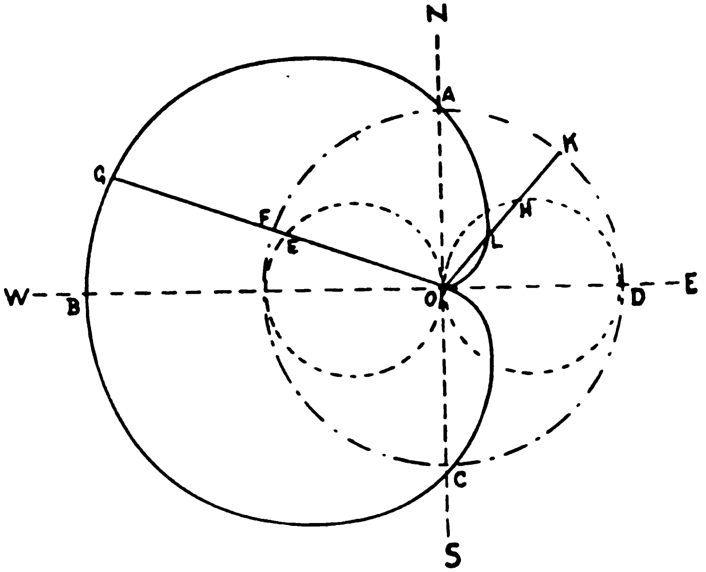
It follows that for any signal coming from a westerly direction the total current in the intermediate circuit will be the *sum* of the currents induced in it by the two aerials—open and loop; and further, for any signal from an easterly direction, the total current will be the *difference* between these two currents, since the sense of the current induced from the loop will be reversed by 180°.

The polar curve of this combination of aerials may be obtained as in fig. 344.

The polar curve of the loop aerial is shown dotted, and that of the open aerial, chain-dotted. It is assumed that the receptivity of the open aerial is equal to that of the loop in its best position, so the radius of the open aerial's circle is taken equal to the diameter of each of the loop's circles.

The full line curve shows the total receptivity of the combination; it is obtained by adding all radius vectors to the west of north, and subtracting those to the east of north. Thus, the point G is obtained by adding the vectors OE and OF; the point

L is obtained by subtracting OH from OK; at A and C there is no current due to the loop, so the vectors OA and OB are equal to the radius of the open-aerial circle.

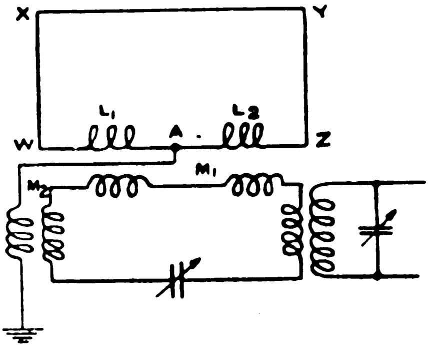


*Heart-shaped Polar Curve of Sense-finder Circuit.*
FIG. 344.

At OB the signal strength is exactly double that due to either aerial alone, while in the opposite direction the two currents exactly cancel out, since the two aerials are assumed to induce equal currents into the intermediate circuit.

This curve is termed a " cardioid " or " heart-shaped " curve, for obvious reasons.

**607.** In practice it is not usually necessary to erect a separate open aerial; the loop aerial itself may be made to act as one, as in Fig. 345.



*Sense-finder Circuit with open Aerial eliminated.*
FIG. 345.

We saw in the last chapter that any wireless wave would induce voltages in the two sides of the loop WX and YZ, and that these voltages partly or wholly neutralised one another in their action round the loop, according to the direction of the wave.

If, however, we tap off a connection to earth from the centre of the loop, as at A, we shall get a current flowing which is due to the sum of these two voltages, whatever the direction of the wave may be; in other words, the loop, as a whole, acts as an open aerial.

The loop, therefore, acts both as an open aerial and as a loop, and the circuit of Fig. 345 is equivalent to that shown in Fig. 343.

The above principle, with certain modifications, is applicable to any of the three systems of direction-finding previously described.

**608. Applications of D/F.**—The D/F installation may be placed either ashore or in a ship.

When placed ashore a ship or aircraft calls the station and transmits for a short time while the D/F station fixes her bearing; the bearing is then signalled through any convenient shore station.

When installed in a ship, bearings are taken either on any shore station who happens to be transmitting, or on a "**beacon**" station; *i.e.*, a station which transmits continuously for this sole purpose.

Shore D/F stations should be able to take bearings more accurately, since they can be erected under ideal conditions, free from the metal structures that occur in ships. Their staffs, solely employed on D/F work, will probably be more highly skilled than ship operators, who have to combine D/F work with their other duties.

On the other hand, there is a very important military reason for placing the D/F set in the ship, viz., that the ship can fix her own position without making a signal at all and so disclosing her position to an enemy, who may be waiting for an opportunity to take her bearing also.

Further, a D/F installation in a man-of-war has certain tactical applications. It may be used for taking the bearing of any enemy ships that make a signal, or for assisting scattered units of the same fleet to find one another under conditions that make the more ordinary methods of navigation difficult.

## Directional Transmission.

**609.** Directional Transmission denotes wireless radiation concentrated in one direction, as opposed to radiation which is, approximately, equal in all directions.

The first attempts at directional transmission were made at an early period in the history of Wireless Telegraphy, by the use of a long and comparatively low aerial, useful directional results being obtained when the length of the aerial reached about ten times its height.

The polar radiation curve of this type of aerial is roughly oval, the energy transmitted in its best direction being about twice the amount transmitted in the reverse direction and about four times the amount transmitted in the directions at right angles.

This particular form of aerial is less difficult and costly to construct than one which would give a similar amount of radiation equally in all directions, and is still in very general use for high power stations intended for point to point working in one direction.

**610.** Another arrangement is to use a loop or frame aerial.

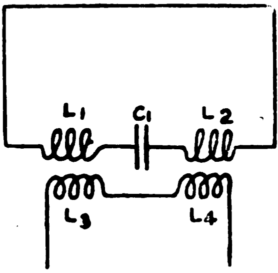


FIG. 346.

A loop aerial, as in Fig. 346, tuned by the condenser $C_1$ and inductances $L_1$ and $L_2$ to the desired wave, and energised from a wireless circuit through the inductances $L_3$, $L_4$ will have a polar curve of transmission similar to its polar curve of reception shown in Fig. 338 (*a*) above.

In a direction at right angles to the plane of the coil the radiation will be zero, because at any instant the current in one side of the loop is in an opposite direction to the current in the other side, so that the electro-magnetic fields generated by each side are exactly 180° out of phase and annul one another, so far as radiation is concerned; the fields set up round the loop are therefore termed " stationary."

In the plane of the aerial the two fields are not out of phase by 180° on account of the length of the loop, one field attaining its maximum after the other, and consequently there will be radiation in this direction.

Consideration of this principle will show that radiation will vary from maximum in the plane of the loop to zero at right angles to this plane, as indicated by the " figure-of-eight " polar curve.

**611.** In the above systems of directional transmitters the effect of the design of the aerial is to reduce the radiation in the unwanted direction, and hence to reduce the total radiation.

If the aerial construction is such that the radiation resistance is any large proportion of the total effective resistance, the reduction of radiation resistance will make an appreciable reduction in total resistance, and for a given power supply the aerial current will rise accordingly.

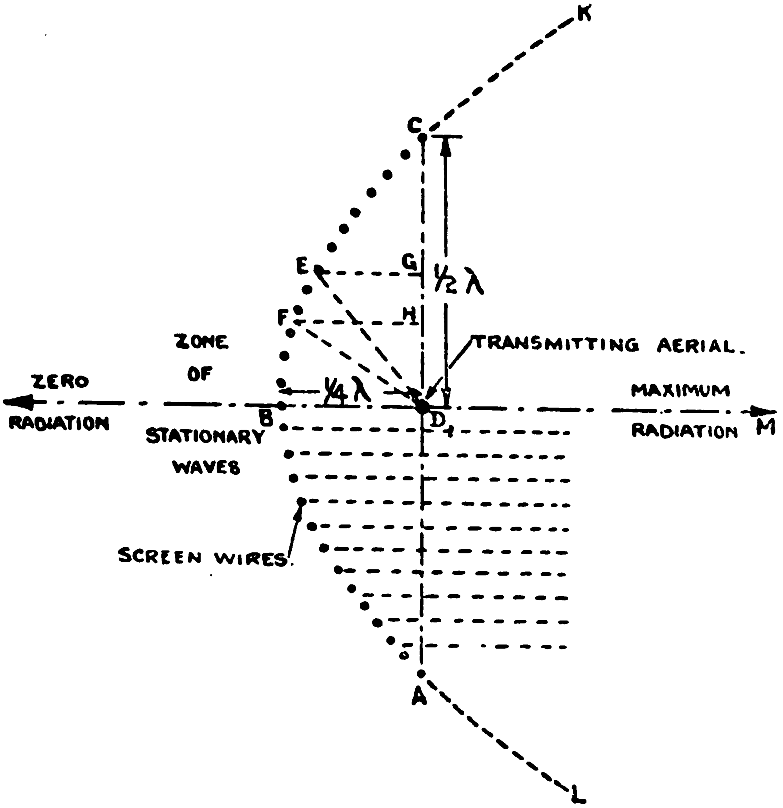
This means an improvement in signal strength in the best direction at the expense of other directions, but the radiation in the best direction is not more than would have been obtained from an all-round aerial of the same height and the same aerial current, although it can be obtained for less power.

It is, however, possible to concentrate the emission of an aerial in one direction and obtain true reflection comparable with optical reflection. This is achieved by the use of a " reflector."

**612. The Reflector System.**—Fig. 347 represents a plan view of a reflector system. The reflector consists of a number of wires each carefully tuned to the required wave ($\lambda$), and suspended from masts along the arc of a parabola A B C.

The transmitting aerial (D) is placed at the focus, which is at a point a quarter of a wave-length ($\frac{1}{4}\lambda$) from the " vertex " B.

The line A D C represents the " aperture " of the reflector.



*Action of a Wireless Reflector.*

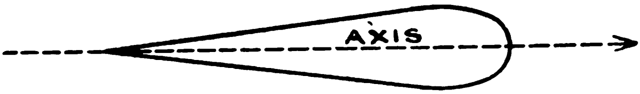
FIG. 347.

**Action.**—When the aerial D is energised each of the reflector wires will also be set in oscillation.

Since the distance BD is exactly equal to $\frac{1}{4}\lambda$, the radiation from the wire at B reaches the aperture exactly in phase with the direct radiation from the aerial D.

Further, it will be found that each of the distances DF + FH (*i.e.*, the distance from a screen wire to the aerial added to that from the screen wire to the aperture) is equal to the distance DB + BD.

Consequently the radiation from all the screen wires will also be in phase with the direct radiation from the aerial and will re-inforce it along the line of maximum radiation BD $M_1$ as shown in Fig. 348.



*Polar Curve of Parabolic Reflector.*

FIG. 348.

Behind the mirror the field from the aerial will annul the radiation from the screen wires, and radiation will be zero provided that the screen wires are spaced sufficiently closely.

The beam can be concentrated still more by prolonging the mirror to K and L.

**613.** This method of achieving directional transmission does not reduce the radiation of the aerial, and therefore gives a greater range for a given power and height of aerial than any method previously described.

Since the length of the screen wires must be about equal to one wave-length, reflector transmission is limited to short wave lengths—below 250 metres—on account of the constructional difficulties and cost in making the masts to support the screen.

**614. Applications of Directional Transmission.**—Directional transmission has two principal applications, viz., for purposes of (*a*) communication and (*b*) navigation.

As regards the former, the form of aerial just described may be applied for point to point communication by R/T and W/T.

Its use has the following advantages—

(i) economy in power;

(ii) avoidance of interference to other lines of communication;

(iii) secrecy.

Power can be economised greatly as explained above, by concentrating the energy in one direction, and a reflector may be used at the receiving station for the same purpose.

Directional transmission has the further advantages that it does not cause interference, and can only be intercepted in the area covered by the beam.

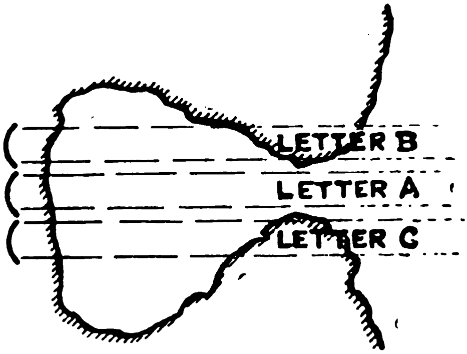
**615. Navigational Applications.**—Directional transmission may be utilised to assist the navigation of ships and aircraft which (*a*) are not fitted with D/F receivers and (*b*) do not wish to transmit for their bearing to be taken by a shore D/F station.

The directed beam may either be fixed or rotating.

In the first case the beam is directed down the line of a channel or passing over a danger to navigation, and some symbol such as a Morse letter is transmitted continuously.

Thus when a ship, tuned to the correct wave, hears the signal, she will know that she is on the bearing which she wishes to follow, or, alternatively, to avoid.

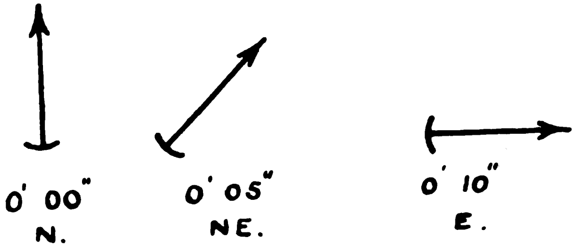
If necessary, two flanking beams may be used, to define the main beam further, as in Fig. 349.



*Use of Reflector Beams at entrance to Harbour.*

FIG. 349.

**616.** In order that a ship or aircraft may be able to determine her bearing at any moment from a given point, a **rotating beacon** may be erected on that point to emit a revolving beam, as in Fig. 350.



*Revolving Beam from Reflector.*

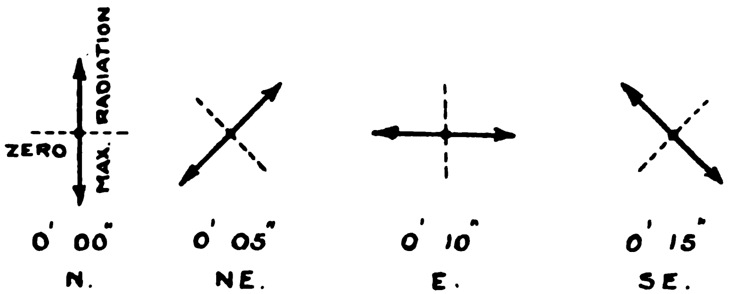
FIG. 350.

The beacon may emit a characteristic signal at each point of the compass, so that the receiving operator can determine his bearing by the signal he hears.

A reflector when used for this purpose suffers from the drawback that its dimensions must be kept small, if it is not to be too unwieldy for rotation. This means that the wave transmitted must be a very short one—of the order of 10 metres or so—which again means that a ship must instal special receiving apparatus to receive this short wave.

**617.** A rotating beacon, to transmit a wave within a range covered by the receiving apparatus generally fitted in ships, may take the form of a simple frame, rotated mechanically about its vertical axis.

The figure-of-eight curve of radiation will then be rotated as in Fig. 351.



*Revolving Beam from Frame.*

Fig. 351.

A convenient system for determination of bearing would be as follows :—

The beam starts at a known time (indicated by a timing signal transmitted from an open aerial) on a known bearing and rotates at a known speed. The receiving operator then, hearing the signal start, notes the time it takes to reach a maximum (or, more conveniently, zero) in his telephones, and calculates his bearing readily.

For example, the beam shown in Fig. 351 commences on the north–south line and rotates from N to E in 10 secs., *i.e.*, 90° in 10 secs. and 360° in 40 secs.

A receiving operator notes that it takes 5 secs. to reach the zero position, adds 10 secs. to give the maximum position (10 secs. + 5 secs. = 15 secs.); his bearing therefore

$$= 360^\circ \times \frac{15}{40} = 135^\circ = \text{SE}.$$

Many similar methods of utilising a rotating beacon may be devised.

# CHAPTER XVIII.

## USE OF THE WAVEMETER.

**618.** This chapter explains how transmitting installations are calibrated by the use of a "wavemeter" so as to transmit various known standard waves.

A wavemeter set consists essentially of a number of known inductances, a calibrated variable condenser, and a device for indicating when the current in the circuit is a maximum.

**619.** The Inductances ($L_K$, Fig. 352) used are sufficient in number to cover, in combination with the adjustable condenser, the full range of LC values in general use. The coils are wound on ebonite formers and enclosed in ebonite sleeves, to save them from damage by careless handling.

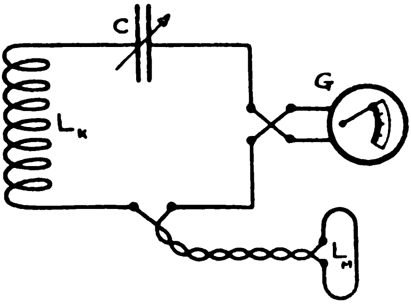


Fig. 352.

They have been calibrated by comparison with standard inductances, and their values are given on a sheet of instructions which accompanies the set.

A calibrated "Mutual" ($L_M$) is also provided for the purpose of inducing current into the wavemeter circuit from any oscillating circuit whose LC value it is desired to measure.

**620.** The condenser is an adjustable air-vane one. It carries a pointer moving over a scale of degrees from 0° to 180°.

It has been calibrated by comparing its value at various positions on the scale with a standard condenser.

A "curve" is supplied with the set giving the capacity of the condenser for any position of the pointer. This curve is a straight line as a rule.

**621.** The device provided for indicating when the current in the circuit is a maximum may take several forms, *e.g.*, it may be (*a*) a thermogalvanometer, (*b*) a lamp, or (*c*) a crystal and pair of telephones.

(*a*) The Thermogalvanometer.—This comprises an ordinary moving coil galvanometer joined across a " thermo-junction."

The " thermo-junction " consists of two fine wires of dissimilar metals—generally steel and eureka—crossed together as in Fig. 353 so as to make a high resistance contact.

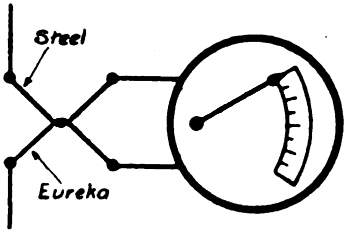


FIG. 353.

When the oscillating current generated in the wavemeter circuit flows across the junction, it is heated up, and owing to the different conductivities of the two wires, electrons flow away from the junction more readily down one wire than down the other.

This results in a steady P.D. between the two terminals connected to the galvanometer, a current through the galvanometer, and a deflection of the galvanometer needle proportional to the square of the oscillating current across the junction and the consequent heat developed.

Sometimes the thermo-junction is enclosed in a glass bulb, with the air exhausted, to protect it from draughts and keep the temperature constant.

(*b*) A low voltage lamp may be inserted in the wavemeter circuit; the coupling of the wavemeter to the oscillating circuit under test should be so adjusted that the lamp just glows when the wavemeter current is a maximum.

(*c*) A crystal couple and pair of telephones in series therewith may be shunted across the wavemeter circuit for the same purpose; the loudness of sound in the telephones will indicate the moment of maximum current in the wavemeter circuit.

**622.** The wavemeter thus provides an oscillatory circuit whose LC value is known for any position of the condenser pointer, and any value of inductance used.

Its use is to measure the LC value of any transmitting circuit—spark, arc, or valve—so that the latter can be adjusted to the required value.

**623. Tuning a Circuit.**—The principle involved is that of resonance between two circuits.

We know that if one circuit is transferring energy to another one, the greatest amount of energy will be transferred when the LC values of the two circuits are equal, for then the current in the second circuit will be equal to $\frac{E}{R}$ instead of

$\frac{E}{Z}$, where $Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$ and E is the E.M.F. applied to the circuit.

Hence the current in the wavemeter circuit will be greatest when it is in resonance with the circuit by which it is being influenced.

Fig. 354 illustrates a wavemeter circuit under the influence of an oscillatory circuit.

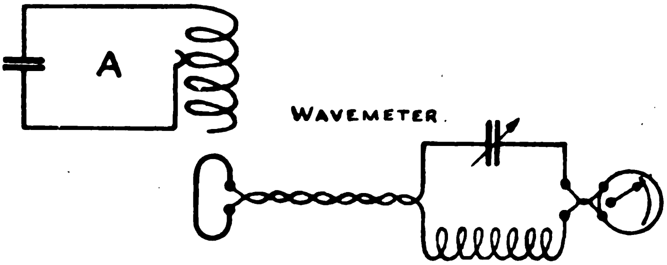


FIG. 354.

It is assumed that the circuit A is being set in oscillation by some means, either spark, arc or valve.

If the wavemeter condenser is varied until the galvanometer reading is a maximum, the two circuits will then have the same LC value.

To tune the circuit A to a certain LC value, the point on the wavemeter condenser scale should first be determined at which the required LC is given.

The inductance of the circuit should then be varied —increased or decreased—until the maximum reading on the galvanometer scale is given when the wavemeter pointer is at this point.

**624. Practical Points in Tuning Spark Primaries.**—The following special precautions should be observed in tuning the primaries of spark transmitting circuits :—

(*a*) Use a coupling between wavemeter mutual and primary which gives a maximum of about half the scale reading on the galvanometer.

(*b*) Use an inductance in the wavemeter of such a value that the required condenser reading will be about midway on the scale.

(*c*) Sparking must be steady and even. The key should be pressed so as to give evenly spaced " shorts "; a continuous " long " should not be made, as the gap will get very hot, and the plugs be burnt away.

(*d*) The plugs should be clean and not pitted.

(*e*) In sets where a revolving gap is fitted this should be kept running.

(*f*) Great care must be taken in adjusting a fixed gap and suiting the A.C. voltage to it. If the gap is too short for the supply voltage, " arcing " will occur; *i.e.*, current from the transformer will flow across the gap without charging the condenser. If too long, one may get a combination of " one spark per cycle," and " one spark per half-cycle," with resultant uneven sparking voltage.

(*g*) Sparking in a wavemeter condenser should not be allowed. This can generally be obviated by earthing the wavemeter casing, and loosening the coupling to the oscillatory circuit.

(*h*) The mutual coil of the aerial circuit should be disconnected.

(*i*) The thermo-junction should be screened from draughts.

**625. Tuning the Aerial—The two Waves.**—The tuning of the aerial circuit of a spark-transmitting installation is a difficult matter, owing to the interaction of the primary and aerial circuits.

It was explained in Chapter VII., para. **321**, that, assuming that the primary and aerial circuits are separately tuned to the same LC value, then owing to the transfer and retransfer of energy between them, viâ the mutual coil, the aerial emits two waves,

$$\lambda_1 = \lambda\sqrt{1 + \text{k}}$$

and

$$\lambda_2 = \lambda\sqrt{1 - \text{k}}$$

where $\lambda$ is the wave-length of the primary or aerial circuit taken alone, and k (the coupling factor) $= \frac{\text{M}}{\sqrt{\text{L}_1\text{L}_2}}$.

These two wave-lengths correspond to two LC values—$\text{L}(1 + \text{k}) \times \text{C}$ and $\text{L}(1 - \text{k}) \times \text{C}$—where LC is the value corresponding to $\lambda$ above.

Hence, if the wavemeter be placed so as to be influenced by either the primary or aerial circuit and the condenser is varied, then two condenser positions (say " $\text{deg.}_1$ " and " $\text{deg.}_2$ ") corresponding to two positions of maximum deflection on the galvanometer will be noticed at the moments when the wavemeter circuit is in resonance with the two LC values mentioned above.

That is, if " $\text{C}_1$ " and " $\text{C}_2$ " are the condenser values corresponding to " $\text{deg.}_1$ " and " $\text{deg.}_2$ " and $\text{L}_\text{m}$ is the inductance in the wavemeter circuit,

$$\text{then } \text{L}_\text{m}\text{C}_1 = \text{L}(1 + \text{k}) \times \text{C},$$

$$\text{and } \text{L}_\text{m}\text{C}_2 = \text{L}(1 - \text{k}) \times \text{C}.$$

**626.** There are two methods used for accurately tuning the aerial circuit of a spark installation :—

(*a*) By spark.
(*b*) By buzzer.

The buzzer method is the easier and more accurate, but installations not fitted with a buzzer must be tuned by the spark method.

**627. Tuning Aerial by Spark.**—Assuming that the primary has first been tuned to correspond with a certain position on the condenser scale, our object is so to alter the aerial tuning that the two wavemeter condenser values—$C_1$ and $C_2$—fall an equal amount on either side of the primary tuning value C; then the aerial will be in resonance with the primary.

Since the curve connecting wavemeter capacity with wavemeter scale readings is a straight line, it is quite safe to assume that the aerial is accurately tuned when the two scale readings —$\text{deg.}_1$ and $\text{deg.}_2$—are an equal amount above and below the scale reading to which the primary was tuned.

The procedure should therefore be as follows :—

(*a*) The first step is to get the aerial approximately in tune with the primary by altering the turns in circuit on the aerial coil until a maximum reading is given on the aerial ammeter.

Then either

(*b*) Make the coupling to the aerial as tight as possible.

Place the wavemeter mutual so as to be influenced by the aerial circuit, and note the condenser positions corresponding to the two maxima swings of the wavemeter galvanometer.

Alter the turns on the aerial coil until these two positions are an equal amount on either side of the positions used for the primary tuning.

Or

(*c*) Loosen the coupling as much as possible.

Place the wavemeter inductance so that it is influenced by the aerial circuit only. In small offices the wave should be measured at the top deck insulator or at some suitable section of the trunk.

Under these conditions if the primary and aerial circuits are exactly in tune, the aerial will transmit a wave of practically single frequency.

If the two circuits are not in tune, both the primary and aerial tuning frequencies or the latter alone may be shown on the wavemeter, and the aerial tuning should be corrected until the aerial has the primary tuning frequency only.

**Example 58.**—The following example illustrates the method referred to in paras. **623** and **627** (*a*) and (*b*) :—

It is required to tune to a wave of 525 metres.

$$\lambda = 62{\cdot}8\sqrt{LC}.$$

Hence $LC = \left(\frac{\lambda}{62 \cdot 8}\right)^2 = \left(\frac{525}{62 \cdot 8}\right)^2 = 69 \cdot 86$ mic-jars.

Inductance used in wavemeter = 120 mics.

Hence required wavemeter capacity $= \frac{69 \cdot 86}{120} = \cdot 582$ jar.

An inspection of the wavemeter curve shows that this is given at, say, 110° on the condenser scale.

The primary should now be tuned to this position as described in paras. **623** and **624**.

Join up the aerial circuit and tune it roughly by aerial ammeter as described in para. **627** (*a*).

Measure the two swings. Suppose they come at 102° and 124°, *i.e.*, 8° below and 12° above the mean.

Reduce the turns on the aerial coil until the swings occur at 100° and 120°, *i.e.*, 10° above and below the mean.

**628. Buzzer Tuning.**—The tuning of a ship fitted with a motor buzzer is a much simpler matter.

This is because a quenching action occurs at the buzzer brushes, and there is no retransfer of energy from aerial to primary, but the energy, when transferred from the primary to the aerial circuit, stays there until dissipated or expended in various ways.

In consequence the aerial oscillates at its own natural frequency only, and neither the tightness of coupling nor the primary tuning make any difference to the wave radiated by the aerial. The only result consequent on the aerial and primary circuits being out of resonance will be that the amount of energy transferred to the aerial circuit will not be a maximum.

Hence buzzer tuning should be carried out as follows :—

Tune the primary circuit by spark as before.

Tune the aerial roughly to the primary by aerial ammeter.

Join up the buzzer in the primary.

Place the wavemeter mutual on top of the aerial coil.

Press the transmitting key and vary the aerial tuning until the maximum galvanometer swing occurs at the same condenser position as that to which the primary circuit was tuned.

The primary has now been tuned by spark, and the aerial by buzzer, to the same wave.

A slight correction has to be made to find the primary tuning position for buzzer, on account of the extra inductance added in the primary circuit by the leads from the buzzer brushes to the spark gap.

This can easily be obtained by keeping the aerial circuit unaltered and varying the primary inductance until a maximum reading is obtained either on the aerial ammeter or on the wavemeter galvanometer.

**629. Measurement of Coupling.**—Sometimes it is required to measure the coupling factor, or the percentage coupling, given at certain positions of the mutual coil when the primary and aerial circuits have both been tuned to the same value.

Let us suppose that LC is the value of the primary and aerial circuits taken separately, that $L_m$ is the inductance used in the wavemeter, and that $C_1$ and $C_2$ are the two wavemeter condenser values corresponding to the two positions—$\text{deg.}_1$ and $\text{deg.}_2$—at which the two maxima galvanometer swings occur.

Then, as we saw in para. **625**,—

$$L_mC_1 = L(1 + k) \times C,$$
$$L_mC_2 = L(1 - k) \times C.$$

Dividing these two expressions

$$\frac{C_1}{C_2} = \frac{1 + k}{1 - k};$$

cross-multiplying, $C_1 - kC_1 = C_2 + kC_2$.

Hence $k(C_1 + C_2) = C_1 - C_2$;

$$\text{or } k = \frac{C_1 - C_2}{C_1 + C_2} = \text{coupling factor,}$$

$$\text{and percentage coupling} = k \times 100 = \frac{C_1 - C_2}{C_1 + C_2} \times 100.$$

As the wavemeter curve connecting condenser capacity and degrees on the scale is a straight line, we may avoid the necessity of working out $C_2$ and $C_1$, and say

$$\text{Percentage coupling} = \frac{\text{deg}_2 - \text{deg}_1}{\text{deg}_2 + \text{deg}_1} \times 100.$$

Suppose the correct condenser position for the primary tuning adjustment is 90°, and that the following condenser positions for the two waves are found as the mutual coil is pulled away from the primary; then the percentage coupling will be as indicated in the right-hand column :—

| Distance of Mutual from Primary. | $\text{Deg}_2$. | $\text{Deg}_1$. | Percentage coupling $= \frac{\text{deg}_2 - \text{deg}_1}{\text{deg}_2 + \text{deg}_1} \times 100.$ |
|---|---|---|---|
| inches | ° | ° | % |
| 0 | 101·7 | 78·3 | 13 |
| 2 | 101·25 | 78·75 | 12·5 |
| 4 | 100·8 | 79·2 | 12 |
| 6 | 99 | 81 | 12 |
| 8 | 96·3 | 83·7 | 7 |
| 10 | 94·5 | 85·5 | 5 |
| 12 | 93·4 | 86·6 | 3·8 |
| 14 | 92·5 | 87·5 | 2·8 |

These results can be plotted as a "coupling" curve thus :—

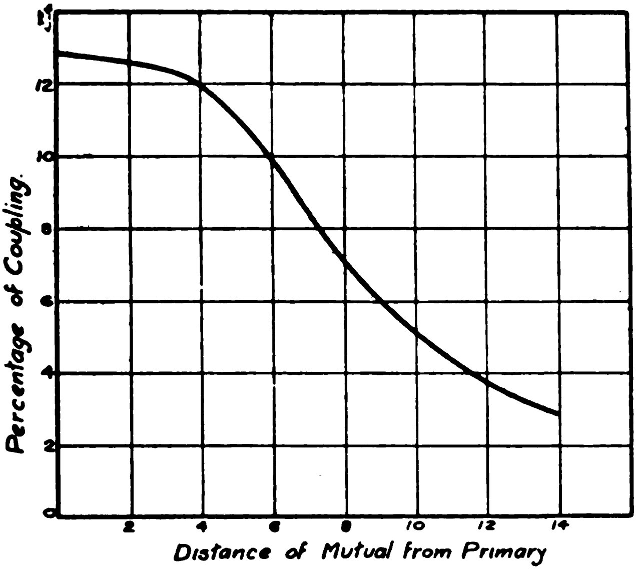


FIG. 355.

Since the coupling factor k $\left(= \frac{M}{\sqrt{L_1 L_2}}\right)$ is different for each wave tuned to—as $L_1$ and $L_2$ alter—a coupling curve showing percentage coupling (or k) against position of mutual (or mutual inductance M) is only true for one wave-length.

In practice it is seldom necessary to go to the trouble of plotting a coupling curve, as Service installations are designed so that the coupling will not be excessively tight when the mutual is close up to the primary.

**630. Measuring Aerial Capacity.**—The buzzer method of tuning gives a simple and fairly accurate method of measuring the capacity ($\sigma$) of a ship's aerial.

Tune the aerial to any given value (say $L_1\sigma$) which will have a corresponding value on the wavemeter of $L_mC_1$; then insert an inductance (L) of not less than 100 mics. from the wavemeter box in series between the aerial and mutual coils and increase the primary inductance as necessary so as to set the primary again approximately in resonance with the aerial.

Measure this second value of the aerial, which will be $(L_1 + L_K)\sigma$ and will have a corresponding value on the wavemeter of $L_mC_2$.

Thus $(L_1 + L_K)\sigma = L_mC_2.$
$L_1\sigma = L_m C_1.$

Subtracting these two expressions, we have

$$L_1\sigma + L_K\sigma - L_1\sigma = L_mC_2 - L_mC_1$$
$$L_K\sigma = L_mC_2 - L_m C_1$$
$$\sigma = \frac{L_mC_2 - L_mC_1.}{L_K}$$

**Example 59.**

$$L_1C_1 = 250. \quad L_2C_2 = 450. \quad L_x = 120 \text{ mics.}$$

$$\sigma = \frac{450 - 250}{120} = \frac{200}{120} = 1 \cdot 66 \text{ jars.}$$

**631.** A second method of achieving the same result may be used if the inductance of the turns added on the aerial coil for tuning to the various waves is known.

This is generally the case in tuning continuous wave installations, as a curve giving this information is given in the handbook of the set.

This method is :—

(*a*) Calculate the inductance added on the aerial coil from the curve given in the handbook.

(*b*) Add any other inductance in the aerial circuit, such as that of the variometer and spacing coil, &c.

(*c*) Divide the LC value of the wave by the figure thus found. This will give $\sigma$.

(N.B.—The natural inductance of the aerial is neglected, but this does not seriously affect the result.)

The following example gives a typical case of this nature :—

**Example 60.**

The following tuning adjustments were obtained in an arc set, with all spacing coil in (160 mics.) and the variometer at zero (110 mics.).

| L.C. | Turns on Aerial Coil. | Inductance of turns added. | Add L of Spacing Coil and Variometer | $\sigma = \frac{L\sigma}{L}$. |
|---|---|---|---|---|
| 1,200 | 35 | 370 mics. | 270 mics. | $\frac{1,200}{640} = 1 \cdot 846$ jars. |
| 3,000 | 73·6 | 1,340 „ | 270 „ | $\frac{3,000}{1,610} = 1 \cdot 863$ „ |
| 6,000 | 125 | 2,950 „ | 270 „ | $\frac{6,000}{3,220} = 1 \cdot 863$ „ |
| | | | | $= 5 \cdot 572$ |
| | | | | Mean. $= 1 \cdot 857$ „ |

**632. Construction of a Tuning Curve.**—When the various tuning positions for primary and aerial have been obtained, it is a good plan to plot them in the form of a curve so that if an intermediate wave is required at any time it can be picked off from the curve.

Let us suppose we have tuned a set, the primary condenser of which has two alternative values, 20 and 40 jars.

The following tuning adjustments were obtained :—

| Wave in metres. | L.C. | Primary Turns with | | Aerial Turns. | |
|---|---|---|---|---|---|
| | | 20 jars. | 40 jars. | | |
| 300 | 22·8 | 1·3 | | 6 | 1·5 jar series condenser used. |
| 400 | 40·5 | 2·3 | | 9 | |
| 500 | 63·3 | 3·3 | | 18 | |
| 600 | 91·2 | 4·75 | | 2 | |
| 800 | 162·2 | 6·2 | | 11·5 | |
| 1,000 | 253·4 | 7·6 | or 3·3 | 21 | |
| 1,200 | 364·9 | | 4·3 | 30·5 | |
| 1,400 | 496·6 | | 5·4 | 40 | |
| 1,600 | 648·6 | | 6·2 | 51 | |
| 1,800 | 820·7 | | 7·1 | 60 | |
| 2,000 | 1,014 | | 7·8 | 68 | |

These results can then be plotted as in Fig. 356 showing the turns used on the primary and aerial coils.

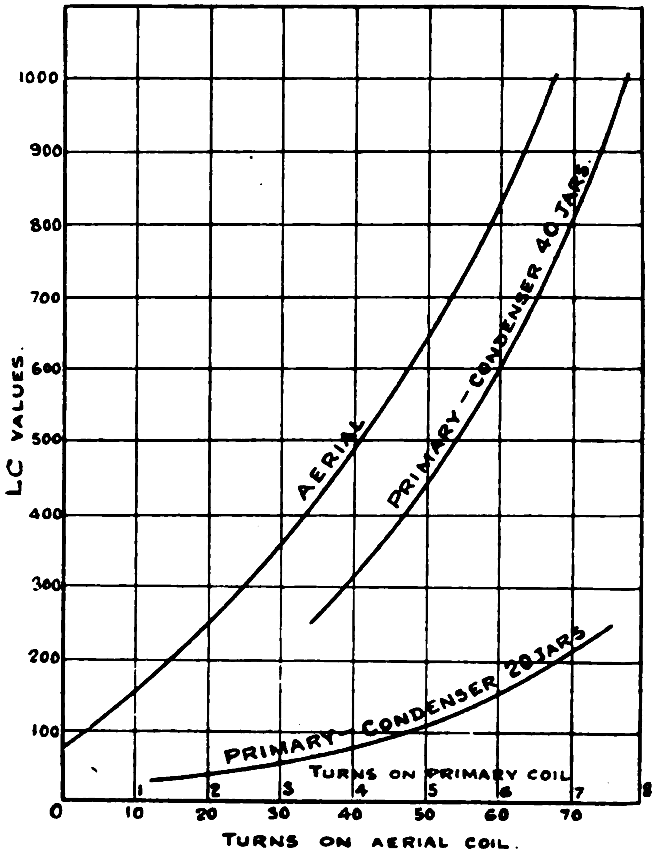


Fig. 356.

**633. Tuning of Short Waves.**—It is frequently necessary to tune to a wave shorter than the fundamental wave of the aerial.

If the required wave is not very much shorter than the fundamental a condenser can be connected in series with the aerial, below the mutual coil.

The aerial should be tuned by the method described in para. **627** (*a*) and (*c*).

If however, the required wave is a short one, it is often difficult to reduce the aerial capacity sufficiently by the insertion of a series condenser : it is impossible to do so if the aerial has a long lead between decks and has a large capacity to the side of the trunk.

The state of affairs is then as represented in Fig. 357, where $C_1$ represents the capacity between the feeder and trunk, $C_2$ the capacity of the roof portion of the aerial to earth, and $C_3$, the artificial condenser added in series.

It can be seen that $C_1$ is in parallel with the joint effect of $C_2$ and $C_3$ taken in series, and so the resultant capacity must always be something greater than $C_1$.

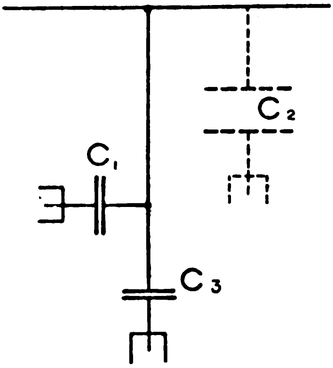


Fig. 357.

In this case it is best to rig a special short aerial for transmitting short waves.

**634. Tuning Continuous Wave Installations.**—Tuning continuous wave installations—both arc and valve—is an easy matter, as only one wave is emitted. Great accuracy in tuning can be obtained and should be insisted on, as with the long waves used a very small error in the position of the wavemeter condenser will lead to a very big error in the result.

It has been found in tuning valve transmitters that the **length of the wave** radiated is liable to be affected by any one of the factors given below, in addition to a variation of the aerial inductance, and these changes may be serious if a **very short wave** is being used.

When any one of the changes below is made, the **wave-length decreases** :—

(1) Decrease of steady grid voltage.
(2) Decrease of anode voltage.
(3) Decrease of coupling of grid circuit to aerial circuit.
(4) Increase of aerial damping.
(5) Increase or decrease of filament current from the point which gives the **maximum** wave-length.

**635. The Heterodyne Wavemeter.**—This instrument consists of two essential parts—

(*a*) a device for producing oscillations at the required frequencies;

(*b*) an arrangement whereby these oscillations can be combined with the oscillations whose frequency is to be measured, to give a note in a pair of telephones.

In other words, a heterodyne wavemeter is arranged as an auto-heterodyne circuit.

If the two oscillations are of slightly different frequency they will give rise to beats which will cause a musical note in the telephones (as already explained in Chapter X.). One or other oscillation is then adjusted so that the note is made lower in pitch until it finally becomes inaudible, *i.e.*, the instrument is adjusted to the " dead space."

The " dead space " covers a definite interval on the scale of the instrument and the two points at which the note just becomes audible can easily be ascertained. Finally the point midway between the boundaries of the " dead space " gives the point at which the two oscillations are in exact agreement.

**636. Applications.**—The heterodyne wavemeter may be used either—

(*a*) to tune a transmitting circuit; or
(*b*) to tune a distant station.

To tune a transmitting circuit the wavemeter is set exactly to the required wave-length, and the tuning of the transmitter altered until the " dead space " occurs at this point.

To tune a distant station the wavemeter is connected to the receiving gear and set as before to the required wave; the distant station then transmits and is directed by signal to increase or decrease his wave-length until the " dead space " coincides with the correct point on the wavemeter scale.

**637. Calibration of Heterodyne Wavemeter.**—A heterodyne wavemeter will be issued with the calibrated values in wave-length marked on its condenser scale, but these values will only be true when a certain valve is used with certain values of anode and filament current.

When the valve which was issued originally is burnt out, the calibrated values as marked will not be quite correct.

Alternatively it may be desired to calibrate an ordinary heterodyne circuit which has not been calibrated before.

For this purpose certain stations belonging to the three fighting services transmit standard waves according to a definite programme, once or twice a month.

It is usual to set the transmitter as closely as possible to the desired wave-length, and then check the actual wave-length of the transmitted signal by means of a standard wavemeter. A message is then sent out advising stations concerned what wave-length has actually been transmitted.

The standard waves actually sent out are recorded in the first instance on the heterodyne by listening out, and the reference points thus obtained may conveniently be recorded in pencil on the scale of the instrument.

Further reference points may then be obtained as follows :—

Any convenient C.W. transmitter is tuned accurately (by listening in) to the waves thus obtained (say 2,800, 2,000, 1,600 and 1,400 metres).

The C.W. transmitter is then set to one of these wave-lengths (say 2,000 metres) and the heterodyne is set to approximately half this wave-length.

It will be found that a note can be heard which is due to the second harmonic of the original oscillation, and the heterodyne is carefully adjusted to this wave (1,000 metres).

The result gives a new reference point which corresponds to a wave-length equal to half the original wave-length : other wave-lengths corresponding to one-third or one-quarter of the original wave-length can be determined in the same way.

Similarly, a further series of reference points may be obtained by tuning the transmitter to wave-lengths equal to double the known wave-lengths on the heterodyne.

In this manner the whole scale of wave-lengths used in the Service may be covered, starting from the few standard waves as originally transmitted.

# CHAPTER XIX.

## CARE AND MAINTENANCE OF W/T INSTALLATIONS.

**638.** This chapter summarises the various precautions that must be taken to keep a W/T set in efficient working order.

The rating in charge of any installation should always bear in mind that it is his duty to keep every set in a state of instant readiness for use.

A set deteriorates very rapidly if neglected, and should be subjected to periodical overhauls.

**639. Rotating Machinery. General.**—The following remarks apply to Motors, Motor Alternators, Motor Generators, and Rotary Converters.

There are two principles which must be observed in the care of electrical machinery, if maximum efficiency is required with the minimum of trouble.

The first is that absolute cleanliness of all parts, particularly the commutator and brush gear, is essential.

The second is that any defect, however trifling, should at once be investigated and remedied.

Machines must be kept as free from damp as possible, and no water allowed to drip or splash on them.

Dirt and dust are liable to collect between the bars of the armature and on the field magnets, and should be occasionally blown out with a pair of bellows.

If the armature or field magnets are carrying more current than they are designed for, or the ventilation is being restricted in any way, the machine will get unduly hot, which will damage the insulation and may melt the solder on the connections.

These parts should therefore be felt occasionally with the hand to ascertain that they are cool, the machine being stopped for this purpose.

Never strike a field magnet pole piece or yoke with any metal.

Use a copper oil feeder for the bearings and do not bring an iron implement near the armature of the machine when running, as the armature is a powerful magnet.

The overhaul of alternators and motors should be regular.

Alternator armatures should be cleaned and brushes reset during the week immediately after running, so that the machine is ready as soon as possible again in emergency.

Duplicate machines should normally be run alternately so that each gets the same amount of work.

Every machine in charge of the telegraphist staff should be run weekly. If electrical power is not available, the armatures should be turned by hand. (A case is on record in which a booster failed to start when power was switched on: on inspection, the fault was found to be that rats had built their nests under the armature.)

When it is necessary to lift an armature, precautions must be taken to prevent damaging the shaft or the windings.

The bearing portion of the shaft should be covered in sacking to avoid scoring by the wire strop in lifting.

Wooden chocks should be placed against the windings to prevent the wire strop cutting them, and sacking should be placed over the outside of the armature to protect the windings in transit.

The field leads must be disconnected before any attempt is made to remove the upper half of the carcase.

When painting machines, avoid filling up the ventilation holes with paint.

**640. Care of Commutators.**—Commutators must be always perfectly clean and true. If sparking occurs at the brushes the commutator will get black, and unless this is removed the sparking will get worse.

Never use emery cloth on a commutator. It should be cleaned with a rag damped with mineral oil or some cleaning solution, or, if in a bad state, by glass paper.

If one particular spot on the commutator be rubbed with glass paper, that part will be made flat, and sparking will always occur there until the commutator has been turned down in a lathe; therefore if cleaning the commutator with glass paper when the machine is stopped, always remove the brush-holders and use a long strip of glass paper so as not to alter the round shape of the commutator.

The best way to clean a commutator is to do so when the machine is running, as it is not so likely that a flat will then be formed.

The commutator should, however, never be cleaned with cotton waste when the machine is running.

If brushes always bear on exactly the same place on the commutator they will wear a groove on that part, causing sparking when the ship is rolling.

The brush-holders should therefore be occasionally shifted along the rocker so as to wear down all parts of the commutator equally.

**641. Causes of Sparking**:—

(*a*) **Brushes and Brush-holders.**

(i) Rocker not in correct position.
(ii) One set of brushes taking too much current due to the other set not bearing properly or having a bad connection.
(iii) Brush-holder placed on a slue.
(iv) Brush-holder put on wrong way round.
(v) Brush-holder not rigid.

- (vi) Insufficient pressure on brush.
- (vii) Brush not free in holder.
- (viii) Brush not properly bedded down.
- (ix) Edge of brush broken away.
- (x) Dirt collected on edge of brush.

(*b*) **Commutators.**

- (i) Dirty.
- (ii) Mica insulation standing up above the copper of the strips.
- (iii) A flat place on the commutator which has been formed by continuous sparking or improper use of emery cloth.
- (iv) The formation of a shoulder round the commutator, against which one of the brushes is bearing.

(*c*) **Armature.**

- (i) Too much play in the bearings.
- (ii) Armature taking too much current due to an overload or an earth.
- (iii) A broken coil or end connection.

  (This will cause a heavy sparking in one place, which will eat away the commutator strip, and which is easily distinguishable from sparking due to other causes.)

Sparking generally occurs if a machine has not been run for some time and is situated in a damp place.

**642. Bedding Down Brushes.**—The surface of brushes must be exactly the shape of the commutator to prevent sparking, and when putting in new brushes, they should be bedded down to that shape.

This can best be done by putting the brush in the holder and placing a piece of glass paper between the brush and the commutator.

By pressing down on the brush and turning the armature and glass paper in the **direction of rotation,** the brush can be worn down to the exact shape of the commutator.

The armature should not be worked backwards and forwards, as the brush, not being an exact fit in its holder, will be cut unevenly.

**643. Bearings.**—Too much attention cannot be paid to bearings and their proper lubrication.

Four faults out of five are generally traceable, in one form or another, to bearings.

It is most important, therefore, to see that the bearings are properly lubricated, but that does not necessarily mean that they should be smothered in oil.

**Lubrication of Bearings.**—The oil ring method of lubrication is almost universal. The ring hangs on a shaft and dips into an oil well.

As the shaft revolves it carries the ring round and the latter brings up oil from the well to the shaft.

Before starting a machine make sure that the oil well is full and that the slip rings are free and in place.

Oil wells have a filling hole and a drain hole; also, in some cases, an overflow pipe.

To fill the oil well, pour in oil until it comes out of the filling hole or overflow pipe. Be very careful not to put in too much, or it will run over to the armature and damage the insulation.

If there is no leakage the oil well should seldom require the addition of any oil after it has once been filled.

At regular intervals, however, say, once a quarter—the oil must all be drained out and fresh oil put in.

An oil ring is liable to stick from any of the following causes:—

(*a*) If the oil is dirty.

(*b*) If the ring has been bent or dented when stripping the motor.

(*c*) If the ring presses against one side of the groove in the bearing.

If the ring is allowed to remain stuck the shaft will wear a groove in the ring at the spot where it is resting on the shaft, and this will cause the ring always to stick at this point.

The ring sometimes jumps out of its slot and rests on the top of the bearing; the shaft then, of course, gets no more oil.

Never leave the lid of the sighting hole to the bearing open.

Mineral oil from the ship's stores should be used in all cases.

**644. Stoeffer's Lubricator.**—This lubricator is filled with mineral grease, and the cup presses the grease into the bearings. When full, the cup should be screwed on with a couple of threads only engaging. When the motor is running, an occasional half turn of the cap should be made so as to keep up the pressure on the grease as it gets used up.

**645. Armature Windings.**—In the case of a very high-speed machine the armature windings sometimes work out of their slots owing to centrifugal force. If they rub against the pole faces their insulation will be damaged and a short circuit will ensue.

In the case of alternators and rotaries, the connections from the armature winding to the slip rings sometimes get so hot as to melt the solder and come out of the holes they should fit into.

**646. Inspection.**—An alternator or motor should be frequently inspected when running under load to see that the following are correct:—

(*a*) That the brushes are not sparking.

(*b*) That the armature and coils are not overheated.

(*c*) That the motor is not taking too much current.

(*d*) That the bearings are cool.

(*e*) That the oil rings are working correctly and that no oil is leaking.

**647. Use of Blow Lamp.**—A W/T rating is frequently called upon to use a blow lamp for making sweated connections, and this is by no means an easy matter.

The blow lamp generally supplied consists of a spirit lamp and a boiler with a fine nozzle below and a relief valve above.

A measure for filling the boiler and a rimer for cleaning out the jet in the nozzle are also supplied.

Methylated spirit is put in the boiler and the lamp and the latter lighted; when the pressure inside the boiler is sufficient, a fine jet of burning methylated vapour will spirt out from the nozzle, and can be directed where required.

**Precautions in working.**—Only fill the boiler with the measure supplied, or only half full.

Keep the jet clear.

See the relief valve on top working freely.

**Soldering.**—Clean the two parts to be joined very thoroughly and see that they are absolutely free from grease. Heat up both parts as hot as is safe consistently with not damaging any insulation. The flux used should be a paste made of pure resin, and methylated spirits. "Rozinal" and "Fluxite" should be avoided. Melt the solder on, keeping all parts as hot as possible.

**648. Spark Transmitting Installations—D.C. Circuits—**Starters, if carelessly handled, are liable to develop wear on the first or second contacts.

The brush contact should be kept true and square, a spare being shipped when necessary.

Dust must not be allowed to accumulate in the resistances of starter and field regulators; it can be blown out with a pair of bellows.

When starting a heavy alternator, always run the motor field regulator right back, otherwise the motor will take an excessive current on starting up, and the overload coil on the starter will trip the holding-on coil.

Check the adjustments of all solenoid-operated instruments carefully; they should agree exactly with the adjustments laid down in the handbook of the set in question.

If the adjustments are incorrect, the instruments cannot be expected to perform the duties for which they are designed.

The current-carrying contacts of such instruments should be inspected frequently, and, when burnt away, either trued up with a file or replaced by a spare.

Never switch on a small auxiliary motor by a D.C. supply switch when a starter is provided. This throws a most unfair strain on the motor; the starter would not have been supplied if a switch had been sufficient.

See all D.C. wiring run carefully, with proper connections to each instrument. The wire should be run as directly as possible, and so that every lead is easy to trace.

The lead casing should be properly connected to the clips provided on the casing of each instrument.

In cutting the lead casing leave some insulation projecting and be very careful not to cut through the insulation also.

In wiring a distributor box, it is a good plan to paste a piece of paper inside the box stating where each pair of leads goes.

Keep D.C. wiring in the silent cabinet well away from receiving leads, otherwise the hum of the ship's dynamo may be heard in the telephones.

**649. Low Tension A.C. Circuit.**—The remarks made above about wiring apply equally here. Be very careful in making connections to use properly sweated cable eyes; do not just twist the wire round the terminal.

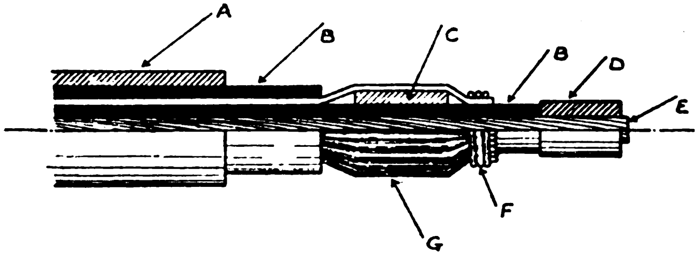
All cable used must be lead cased, otherwise it will be impossible to receive when the machine is running.

As a rule, concentric cable is used for running all A.C. wiring, its advantages being :—

(*a*) It is non-inductive.

(*b*) It requires only one hole to be made in any bulkhead through which it passes.

The method of connecting it is illustrated in Fig. 358.



REFERENCE.

| | |
|---|---|
| A. Lead casing | E Inner conductor |
| B. Rubber insulation | F Binding wire |
| C Brass ferrule | G. Outer conductor |
| D. Brass ferrule (soldered) | |

FIG. 358.

The lead casing of the concentric cable must be well gripped by the earthing clamps, and must end flush with the inner side of the clamp. The insulation between the lead casing and the outer core must be carefully protected from damage while cutting off the lead casing.

In all cases as much length of rubber insulation should be left undisturbed as the design of terminals will allow.

Two ferrules are supplied for each pair of terminals for concentric cable.

The ferrule with a large hole through its centre is intended to slip over the rubber insulation between inner and outer conductors and under the strands of the outer conductor.

The ends of the strands are then bound round with fine binding wire to keep the ferrule in place; no solder should be used, or the insulation will be damaged.

The ferrule with the small hole in it is soldered on to the inner conductor.

The two ends thus formed are clamped in the clamps provided on the instrument to which the connection is being made.

**650. Transformer and High Tension Circuit.**—Remember that the transformer must be given every opportunity of radiating its heat away; it should therefore have a clear air space left all round it.

Wipe it over occasionally to keep it free of oil.

The transformer insulators, and all other insulators carrying the high tension leads, must be kept absolutely clean to avoid leakage losses.

**651. The Oscillating Circuit.**—**The Condenser** must be kept free from oil on top, its insulators clean, and its terminals making good connection with the remainder of the circuit.

The safety gap fitted must be kept set to the correct distance to prevent puncture.

If smoke issues from the inside, this is an indication that one or more dielectrics have punctured.

Then remove the lid, lift out the elements, bale out the oil, dry the tank out thoroughly with cotton waste first and finally by burning a yardarm group or a radiator inside; remove all traces of dirt or cotton fluff from inside; replace the damaged element by a spare, and rebuild the condenser; be very careful to make all connections well and not to break off any tabs from the condenser plates; fill the condenser with fresh insulating oil; leave it for at least 8 hours before sparking into it.

If, when retuning the primary at any time, it is noticed that the primary inductance required is much more than that for the previous adjustments, this is an indication that some condenser tabs have become disconnected inside and require repairing.

If an oil gauge is fitted, see it is placed with the "Safe to Work" mark level with the upper edge of the flange round the top of the condenser tank.

**The Spark Gap** requires very regular attention; the electrodes must be kept as smooth as possible; when badly worn they must be replaced. The insulators will get covered with copper dust which must be wiped off, otherwise a big leakage loss will occur.

Synchronous and asynchronous gaps must be set to have the minimum clearance possible; this always gives the best results. Be very careful that none of the moving electrodes foul the fixed ones.

When renewing the fixed electrodes of asynchronous gaps, they must be shipped in such a manner that the sharp edge forms the leaving edge for the spark.

In the case of a **Synchronous Gap,** the stationary electrodes must be slowly moved in each direction until a position is found at which the moving electrodes appear to be standing still if watched while the key is pressed.

When this is the case, the spark is taking place at exactly the same position each time it occurs, and the eye thus photographs the rotating electrodes in the same position.

If the fixed electrodes are incorrectly set, the moving electrodes appear to stagger about and become blurred.

**The Primary Inductance** must be kept clean and free from grease and verdigris.

When shifting wave, the adjustable connection must not be forced off or on, but should be unscrewed and screwed up carefully.

**652. The Aerial Circuit.**—The most important point to remember in connection with the aerial circuit is that the circuit has to have as low a resistance as possible for an **incoming** wave. After tuning, clean the wire of the aerial coil very carefully at the points determined by tuning, and screw up the tuning clips tight.

Make the connection to the mutual coil very carefully. Use sweated cable eyes everywhere.

Sling the aerial coil so that it cannot move much when the ship is rolling, and so that there is no chance of it brushing to any earthed object.

There is no great advantage gained in making connections to and from the aerial coil with copper tubing, which by its rigidity is rather liable to strain the terminals to which it is connected; three strands of patt. 611 wire twisted together are quite sufficient.

Be careful not to burn out the aerial ammeter; an adjustment is generally provided whereby a full scale deflection may be obtained on power or buzzer; do not forget to set this before transmitting on power.

Be careful that the send-receive contacts make well, and have clean surfaces.

Keep the deck insulator scrupulously clean inside and out; it should be wiped over as a matter of daily routine, using a clean rag and warm fresh water.

The insulators in the trunk should be tested with a bridge megger weekly, also after coaling and heavy gunfire. Insulation frequently becomes covered with moisture, particularly if the trunk is led near a galley or other hot compartment.

**653. The Aerial.**—Read Chap. XVI carefully.

Take the greatest possible care in constructing the aerial to have good connections everywhere and to leave no projecting ends of wire.

Establish a regular routine of cleaning outhaul and strain insulators.

If sparking occurs at any rigging insulator, short-circuit it with a piece of wire.

Test the insulation resistance of the aerial regularly with a bridge megger by disconnecting the aerial coil from the aerial and balancing the insulator resistance to earth. If this is low, go to the top deck insulator, disconnect the between-deck feeder and balance again; the point of the bad insulation may be located in this manner.

A better test than the bridge megger is the use of the emergency sets on plain aerial: if a good spark cannot be obtained, the aerial insulation is defective somewhere.

**654. Poulsen Circuit.—Aerial Circuit.**—Most of the foregoing remarks apply equally to the oscillating circuits used with the Poulsen arc.

An arc is very particular about the aerial connections, which must be perfect.

Further, insulation, which will stand high spark voltages perfectly well, breaks down when subjected to the strain of a continuous wave; distrust ebonite, rubber, or vulcanite insulators for this reason.

The aerial coils used with C.W. sets are designed with the minimum clearance between turns to avoid sparking in order to keep their dimensions as small as possible. If, therefore, they are allowed to get damp, or covered in dust, sparking is liable to occur. They must be kept clean inside and outside, and if damp, should be placed in some hot compartment until thoroughly dry; or, alternatively, they may be dried by passing a direct current of not more than 2 amps. through them for several hours.

Never place a coil in front of a radiator or fire in order to dry it. Excessive heat is liable to cause the windings to stretch and sag.

The power input required to get a given aerial current, with both arc and valve sets, should be noted: if it increases for no apparent reason, the aerial insulation should be looked to.

**655. The Arc.**—The arc chamber must be kept very clean inside. The electrode insulators are very liable to get covered in carbon deposit and must be cleaned regularly.

The carbon must be renewed at frequent intervals; generally, half-an-hour's burning of a small arc will necessitate renewal.

Keep the arc chamber absolutely free from air leaks; these are easily tested for with a lighted taper when the arc is burning.

The water tank must be cleared out at least once a quarter, and the fact entered in the W/T log.

**Do not forget to turn the water on.** The water should be renewed every month, otherwise it is liable to get impure and put an earth on the anode.

Pure distilled water should be used. In cold climates glycerine may be added to prevent freezing. Its effects in lowering the freezing point is as follows:—

| Pints of glycerine to gall. of water. | Freezing point. |
|---|---|
| 1 | 26° F. |
| 2 | 19½° F. |

Adjust the arc length carefully for **maximum steady radiation,** and **a steady note** when listening in.

**656. Valve-Transmitting Circuits.**—In valve-transmitting circuits the greatest possible care must be taken of the valve itself.

It should always be handled with the greatest care, and never removed from its box unnecessarily.

The correct filament voltage as marked on the valve label should be adhered to, or slightly increased when the valve has been in use some time.

The anode should be watched for signs of over-heating; this is an indication that it is having to dissipate an excessive amount of power.

If it occurs immediately on switching-on, the most probable cause is that the aerial is not oscillating, and the fault must be sought for and remedied. If the cause is a wet insulator, use a high anode tapping point and make shorts. This will dry the insulator and allow oscillations to be established.

If it occurs after a long spell of signalling the applied voltage should be lowered.

When a rectified A.C. supply is used, the fault may be that the filament current of the oscillating valve needs to be increased (*see* Chap. XIII., para. 522).

**657. Receiving Circuits.**—The two losses that have to be guarded against are—

$I^2R$ losses in conductors;
losses through faulty insulation resistance.

For good conductivity, bare copper wire or multi-stranded wire should be used, and all connections to instruments must be carefully made and the terminals well screwed up.

See that the moving connection of an adjustable inductance makes a good firm contact, but do not screw it up so tightly that it wears the stops away unduly.

Make certain that the insulation from earth is perfect throughout, the most important parts being the aerial and the secondary circuit.

Never make pencil marks between the stops of any adjustable inductance, as these form high resistance paths for current.

Where crystal reception is fitted, having once found a sensitive point on the crystal couple, screw the contact firmly up and then leave it alone.

A carborundum-steel couple does not often "throw-off," or if it does, it soon recovers if left alone.

Carborundum is supplied in small crystals ready to be inserted into the cup of the detector holder; the marked end should be inserted into the fusible metal.

The best results are usually obtained with close-grained carborundum—that is, pieces in which the constituent crystals are small and packed close together.

In the event of no sensitive points being found on the crystal, or if it is of an inconvenient size, the end of the crystal should be broken off.

Some care is necessary in breaking off an unsensitive point so as to leave a clean crystalline end to the crystal. Simply to cut off the end with a pair of pliers is not generally satisfactory, as it leaves a flat shiny surface, consisting of a mass of crystals which have been broken transversely. The better method is to apply the cutting edge of the pliers diagonally, removing the crystal from the cup as necessary. A new surface can then generally be got with projecting crystals whose points have not been broken off.

The steel which is in contact with the carborundum may be a flat surface, a rounded or sharp point.

Copper, brass and graphite have also been used instead of steel with good results.

See that the cells used with the potentiometer have their proper voltage and are not run down.

Each operator should have his own pair of telephones allotted to him, and should disconnect and hang them up at the end of his watch, having first dried the diaphragms.

Faults are liable to develop both in the flexible leads and in the magnet windings.

The small nuts on the telephone terminals are liable to become loose, owing to the movement of the telephone leads.

**658. Valve Receiving Circuits.**—Move all handles carefully, and do not force them if they are inclined to stick. If a defect occurs, carry out the tests as laid down in the handbook.

Keep the filament current down to the value marked on the box, or lower if possible; when the valve has been in use for some time, however, it will probably be necessary to increase the filament current somewhat.

Test the voltages of the high potential battery and filament heating battery frequently.

Never use more than the minimum amplification necessary for reading signals. Unnecessary amplification brings in interference, wastes valves, and runs batteries down.

When inserting a new valve, see that it makes good contact at all four points, and increase the rheostat resistance.

**659. Primary Batteries.**—Dry cells should not be stored in a hot compartment. The heat causes evaporation and the cell loses moisture, with consequent loss of efficiency.

It is advisable to stow cells vertically. The gas generated in the cell by local action can then rise into the air space at the top of the cell.

If the cell is stored on its side the gas forces its way out and bulges the side; the cell then leaks moisture through the crack.

When soldering connections to "Ever-ready" cells, it is most important to use as small and cool a soldering iron as practicable in order to communicate as little heat as possible to the cell.

The use of a large, very hot soldering iron is very liable to ruin the cell.

When taken into use, cells should be filled up with pure distilled water; they should be allowed about half an hour for soaking in the water, and then filled up again. No more water should be added after the second filling.

The cells should be frequently examined to see that no salammoniac solution is creeping out round the terminals, as this is liable to short-circuit the cell.

Any salt or sulphate round the terminals should be removed.

**660. Secondary Batteries or Accumulators.**—Read Chap. II., paras. **65** to **78**, carefully, and observe the precautions given in para. **78**.

The four outstanding rules for looking after accumulators are—

(*a*) Add nothing but pure water to the cells, and do it often enough to keep the plates and bridges covered with solution.

(*b*) Take daily hydrometer readings.

(*c*) Give the battery a special charge whenever these readings show it to be necessary.

(*d*) Keep the vent plugs clear, the connections tight, and the battery clean.

Batteries should be placed on insulated stands to prevent commutation noises being brought in from the battery on charge in case of excessive spraying or leakage of acid.

Charging and discharging leads should be kept as far apart as possible, and should never be closer than nine inches. They should not run parallel to one another if this can be avoided. Failure to observe these precautions may result in commutator and other local noises being brought into the receiving instruments.

(*a*) **Adding Water.**—Water is added to make good that lost by evaporation. It must be added often enough to keep the plates covered; if the plates are exposed for any length of time they may be seriously damaged.

The water should be added just before the cell is charged; then it will get thoroughly mixed with the solution.

The water added must be as pure as possible; distilled water, melted artificial ice, or rain water are recommended.

Never add acid except to make good actual loss by spilling or spraying.

(*b*) **Hydrometer Readings.**—The importance of hydrometer readings is that they indicate whether the battery is receiving sufficient charge; they also indicate the state of discharge of the battery, and when it is necessary for it to be charged.

It was explained in Chap. II. that, as the battery discharges, some of the sulphuric acid combines with the active material on the plates, thus leaving the electrolyte weaker or of lower "Specific Gravity."

The specific gravity for all Fuller cells is 1·17 when first filled. This rises to 1·22 when the cell is fully charged, and falls to 1·15 when fully discharged.

Thus the hydrometer reading is a good indication of the amount of charge remaining in the cell; it is a much better indication than the actual voltage of the cell, which is sometimes misleading.

The reading should be taken by removing some electrolyte from the cell with a syringe and putting it into a test tube or other suitable receptacle, and then noting how far the hydrometer sinks down into it. Then if this reading is much below the correct specific gravity, the cells require recharging.

(*c*) **Charging.**—The battery should be charged when the voltage of any cell with a discharge current passing has fallen below 1·85.

Charging should always be given at the rate stated on the instruction label attached to the battery.

As a rule, valve filament batteries are duplicated and arranged with a "charge-discharge" switch, so that while one battery is being used the other is charging at the same time; this switch should be changed over at the end of each watch.

**Indication of Full Charge.**—Plates a healthy colour—positives chocolate, negatives a light or blue grey, according to age; plates all gassing freely and to an equal extent; specific gravity of acid attained a maximum stationary value; voltage attained a maximum stationary value.

(*d*) **Cleanliness.**—The battery cannot work to the best advantage unless it is kept clean and dry on the surface, and unless the connections are all tight and clean. If signs of corrosion of any brass or copper parts should appear, the parts should be thoroughly cleaned with weak ammonia or soda, and vaseline should then be applied.

When the battery has nearly completed its charge and is gassing freely, a certain amount of acid will be sprayed out through the vent holes. This must all be wiped off as soon as the charge is completed.

**661. Practical Working Hints.**—How to tell if plates are charged too much :—

(*a*) By the colour of the plates; positives too dark, deep brown, almost black; negatives, dark blue grey.

(*b*) By the condition of the plates; spongy lead growth on negatives; contraction or swelling of negative or active material. Positives (pasted type) become pulpy; if charged far too much at high rates the active material of positives will be scrubbed off, and the electrolyte will turn brown on charge.

(*c*) By the acid; the external part of the battery will be sprayed with acid driven off during charging; the specific gravity will be low if water only has been added to make good the loss ot acid.

How to tell if battery is not charged enough :—

(*a*) Colour of plates: light brown or white positives, pale grey or white negatives.

(*b*) By the low specific gravity of the acid.

**662. High Potential Batteries.**—A high potential accumulator battery should be trequently tested at all switch positions, but only occasionally charged, as the discharge current is very small.

A battery in good condition should be given about 18 hours' charge (·05 amp.) in a fortnight.

More current will probably be taken from the battery by internal leakage than by the valve, and all possible care must be taken to keep this leakage low by preventing any accumulation of acid on the cells.

For a first charge, the vents must be removed and not replaced until the spraying of acid shows signs of stopping. This may take three or four days. During this time the lid of the box should be left open, and the accumulation of acid removed at intervals with blotting paper.

It has been found that the spraying of the acid from the vents of the cells of these batteries when charging is very much reduced by pouring about half a teaspoonful of insulating oil into each container.

It is very important not to pour in too much oil, otherwise the bottoms of the vents are covered and the oil is driven up out of the wells.

The spraying is reduced if a day's rest is allowed in the middle of the first charge.

Internal leakage due to the escape of acid from a faulty container sometimes occurs. It is indicated by signs of acid at the joints of the box.

It is a sure sign of leakage when the voltage of one section falls more rapidly than that of the others.

# APPENDIX A.

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## ELEMENTARY NOTES ON ARITHMETIC, ALGEBRA, TRIGONOMETRY AND MECHANICS.

The following signs are in frequent use :—

$\infty$ Infinity.
$\propto$ "Varies as," or "is proportional to."
$\therefore$ Therefore.
$\because$ Because.
$>$ Is greater than.
$\ngtr$ Is not greater than.
$<$ Is less than.
$\nless$ Is not less than.
$=$ Equals or is equal to.
$\times$ Multiply by.
$\div$ Divide by. Also /, $2 \div 3$, $\frac{2}{3}$, 2/3.

The following sections are written to cover the mathematics required for the purposes of this book, and having in view the average attainments of the ratings who will use it. Those having little or no knowledge of what follows and who desire fuller knowledge are referred to a book on mathematics such as Castle's "Practical Mathematics for Beginners."

## ARITHMETIC.

It is assumed that readers have a good working knowledge of the ordinary operations in arithmetic, including fractions and decimals. The following notes are intended to be merely supplementary. If any of the methods are unfamiliar to the reader, he is strongly advised to practise them, to write them out step by step for himself, and not simply read them through.

### Short Methods.

To multiply by 25 : add two 0's (or move decimal point two places to the right) and divide by 4.

$$\mathbf{67} \times \mathbf{25} = 6{,}700 \div 4 = 1675. \quad \mathbf{\cdot 067} \times \mathbf{25} = 6\cdot 7 \div 4 = 1\cdot 675.$$

To multiply by 125 : multiply by 1,000 and divide by 8.

$$\mathbf{2\cdot 03} \times \mathbf{125} = 2{,}030 \div 8 = 253\cdot 75.$$

To divide by 25 : multiply by 4 and divide by 100.

To divide by 125 : multiply by 8 and divide by 1,000.

$$\mathbf{8\cdot 32} \div \mathbf{125} = \frac{8\cdot 32 \times 8}{1{,}000} = \cdot 06656.$$

In division it is simpler to use steps of short division, if possible.

$$e.g., \ \frac{\mathbf{3703}}{\mathbf{64000}} = 3{,}703 \div 1{,}000, \ 8 \text{ and } 8.$$

$$\begin{array}{r|l} 8 & 3\cdot 703 \\ \hline 8 & \ \cdot 462875 \\ \hline & \cdot 057859375. \end{array}$$

Four decimal places in each line would be sufficient for most purposes, *e.g.*, if the result represented the diameter of a fine wire. The result would then have been ·0578. The result "correct to 3 places" would be ·058 (as ·058 is nearer the result than ·057).

Similarly, **1·0698** correct to 2 places is 1·07,
and **1·0628** „ „ 1·06.

If the first figure rejected is 5 or over 5 the preceding figure is increased by 1; if less than 5 no change is made in the preceding figure.

More often than not we are concerned with calculations that "do not work out exactly." Also, to make the working less laborious, and to shorten it, we use logarithms, a slide rule, or contracted methods of multiplication and division.

The latter processes will be described now.

## Contracted Methods.

**Ordinary Method.** **5·0347 × 8·126.**

$$\begin{array}{r:l}
5\cdot0347 & \\
8\cdot126 & \\
\hline
402776 & \\
5034 & 7 \\
1006 & 94 \\
302 & 082 \\
\hline
40\cdot9119 & 722
\end{array}$$

We have multiplied by the 8 first (not the 6 as is commonly done).

Note the unnecessary figures to the right of the dotted line.

**Contracted Method.**

$$\begin{array}{r:l}
5\cdot0347 & \\
8\cdot126 & \\
\hline
402776 & \\
5035 & \\
1007 & \\
302 & \\
\hline
40\cdot9120 &
\end{array}$$

**Steps.**

Draw a vertical line as shown. The first figure of each line of multiplication commences at this line :—

(1) Multiply 50,347 by 8, then cross out the 8 and the 7.
(2) Multiply 5,034 by 1, but first say 1 × 7 to find if there is anything to carry. 1 × 7 = 7; 7 is nearer 10 than 0, so carry 1. Then cross out the 1 and the 4.
(3) Multiply 503 by 2; first say 4 × 2 = 8, nearer 10, carry 1. Then cross out the 2 and the 3.
(4) Multiply 50 by 6; first say 3 × 6 = 18, nearer 20, carry 2.
(5) Determine the position of the decimal point in the answer by inspection, *i.e.*, by making a rough estimate.

To shorten the work still further, proceed as follows :—

$$\begin{array}{r:l}
5\cdot034 & 7 \\
8\cdot126 & \\
\hline
40278 & \\
503 & \\
101 & \\
30 & \\
\hline
40\cdot912 &
\end{array}$$

(1) Reject the 7, but use it for "carrying" in the first multiplication.
(2) 5,034 × 8; first say 8 × 7 = 56, nearer 60, carry 6, and so on, as before.

Answer. 40·91 to 2 places.

It is a matter of judgment and of practice to know how many figures to reject at the beginning. It is not advisable to trouble about rules.

### Contracted Division.

**·50347 ÷ 81·26.**

8126)50347(6195
48756
——
1591
813
——
778
731
——
47
41
—

Ignore decimal points until later.

(1) 8126 into 50347, 6 times, remainder 1591.

(2) Instead of bringing down a figure (0 in this case) cross out the 6 in the divisor.
812 into 1591, once, 1 × 6 = 6, nearer 10, carry 1.

(3) No figure to be brought down. Cross out the 2 in the divisor. 81 into 778, 9 times, 9 × 2 = 18, carry 2, 81 × 9 and 2 = 731.

(4) Cross out the 1 in the divisor. 8 into 47, 5 times, 5 × 1 = 5, carry 1. 5 × 8 + 1 = 41.

(5) To fix decimal point in answer—

81)·50347
·006

Answer. ·006195, or ·0062 correct to four places.

**6·03 ÷ ·02689358.**

The result will be approximately $\frac{6\cdot03}{\cdot026} = \frac{6030}{26} = 231$, and probably only one or two decimal places will be sufficient in the answer. We can afford to cross out the 58 at the beginning.

2689358)60300(2242
53787
——
6513
5379
——
1134
1076
——
58
54
—

(1) 26893 into 60300, twice, 2 × 5 = 10, carry 1.

(2) Cross out the 3, and proceed as before.

Answer. 224·2.

Examples for practice (all by contracted methods):

(1) 2·684 × ·92673, correct to 3 decimal places. Ans. 2·487.
(2) 293·6 × ·0000697, correct to 3 significant figures. Ans. ·020.
(3) ·728 ÷ 19·58, correct to 3 decimal places. Ans. ·037.
(4) $3 \times 10^7$ ÷ 981·6, correct to nearest thousand. Ans. 31,000.

**Cross Multiplication.**—This is a useful method when we have one fraction equal to another.

Its truth is illustrated thus:—

$$\frac{3}{4} = \frac{6}{8}$$

Numerator of first × denominator of second = num. of second × denom. of first—

$$3 \times 8 = 6 \times 4, \textit{i.e.}, 24 = 24.$$

If $\frac{m}{6} = \cdot3$, find the value of m.

$\frac{m}{6} = \frac{3}{10}$, hence $m \times 10 = 3 \times 6$.

$$10m = 18,\ m = \frac{18}{10} = 1\cdot8.$$

$f = \dfrac{4800000}{\sqrt{LC}}$, find the value of LC when f = 830,000.

$$\frac{830000}{1} = \frac{4800000}{\sqrt{LC}},$$

$$830000 \times \sqrt{LC} = 4800000,$$

$$\sqrt{LC} = \frac{4800000}{830000} = \frac{480}{83},$$

$$LC = \left(\frac{480}{83}\right)^2 = 5{\cdot}78^2$$

$$= 33{\cdot}4.$$

$$\begin{array}{r} 5{\cdot}78 \\ 5{\cdot}78 \\ \hline 2890 \\ 405 \\ 46 \\ \hline 33{\cdot}41 \\ \hline \end{array}$$

Judgment is required as to what degree of accuracy to give a result. For instance, the distance between two towns would not be given as 38·26027 miles, or 38 miles and so many yards, feet, and inches. 38¼ miles would be near enough. Nor do we find LC values given to 4 or 5 decimal places (as would be the case for the diameter of a fine wire); for low LC values one decimal place would be sufficient, and, for higher values, the nearest unit.

Again, should we calculate an oscillation frequency to be 923281; to give it as 923000 would be near enough for our purpose.

### An important System of Notation.

For very large numbers and for very small fractions the following notations should be known :—

$$10^6 = 1{,}000{,}000,\ 10^3 = 1000,\ \&c.$$

For $10^6$ we say "ten to the power 6" or "ten to the sixth." "6" is an "index," *i.e.*, it indicates that $10^6$ is the sixth power of 10.

In $10^6$ and $10^3$, the 6 and the 3 are "indices" (plural of index). (Indices will be dealt with again under "Algebra.")

The formula—

$$f = \frac{3 \times 10^7}{2\pi\sqrt{LC}} \text{ will be remembered.}$$

It becomes (when $\pi = 3\frac{1}{7}$) $f = \dfrac{4772727}{\sqrt{LC}}$

$$= \frac{4800000}{\sqrt{LC}} \text{ approx.}$$

$$= \frac{4{\cdot}8 \times 10^6}{\sqrt{LC}} \text{ approx.}$$

Similarly, 923,281 might be written 923,000 approx.

$$= {\cdot}923 \times 10^6$$

$$\text{or } 9{\cdot}23 \times 10^5.$$

### Negative Indices.

$10^{-3}$ (10 to the power − 3) means $\dfrac{1}{10^3}$.

(Similarly, $10^3$ may be written $\dfrac{1}{10^{-3}}$, but the former concerns us most.)

The specific resistance of copper is given as ·64 microhm.

This is equivalent to $\frac{\cdot 64}{10^6}$, or $\cdot 64 \times \frac{1}{10^6}$

or $\cdot 64 \times 10^{-6}$ ohm.

Again, a current of 8 microampères $= \frac{8}{10^6} = 8 \times 10^{-6}$ amp.,

and a current of ·2 milliamps. $= \frac{\cdot 2}{10^3} = \cdot 2 \times 10^{-3}$,

or $2 \times 10^{-4}$ amp.

This system is termed the "Inverse Notation System."

**Examples.**

(5) $f = \frac{3 \times 10^7}{2\pi \sqrt{LC}}$, find "LC" when $f = 3\cdot 5 \times 10^5$ and $\pi = 3\frac{1}{7}$.

Ans. 186.

(6) Find the value of "s" if $\frac{\cdot 9s}{8} = \cdot 4$. Ans. $3\frac{5}{9}$.

(7) $f = \frac{3 \times 10^8}{\lambda}$, find "$\lambda$" when $f = 10^6$. Ans. 300.

**Square Root.**

The square root of a number is that number which, multiplied by itself, gives the given number.

Square root of 9, or $\sqrt[2]{9}$, or simply $\sqrt{9}$, or $9^{\frac{1}{2}} = 3$.

To find the value of $\sqrt{738\cdot 238}$ to 2 decimal places.

```
           7,38·23,80 (27·17 Answer.
           4
           —
  47       338
   7       329
  ——       ———
 541        923
   1        541
 ———       ————
5427        38280
            37989
           ——————
```

(1) Mark off the figures in pairs to the left and to the right of the decimal point.

(2) The square number next below 7 is 4 and $\sqrt{4} = 2$. Put 2 in the answer. Square 2 (= 4), place it underneath the 7, and subtract.

(3) Double the 2 (4) and place it at the left opposite the 3, and bring down the next two figures (38).

(4) 4 into 32, 8 times; but this will be too great, as will be seen from what just follows. Try 7. Place 7 in answer and alongside the 4. Multiply 47 by 7, and subtract.

(We have now finished with the whole number part (738), so the decimal point in the answer will be placed after the 7.)

(5) Repeat the 7 under the 47, and add (or, what amounts to the same double the 27 in the answer (54) and place it at the left.) Bring down the next two figures (23.)

And so on.

If more figures are required in the answer, bring down pairs of 0's at each step.

$\sqrt{\cdot 029}$

| | |
|---|---|
| | ·02,90,00,00(·1702 |
| | 1 |
| | — |
| 27 | 190 |
| 7 | 189 |
| — | — |
| 340 | 100* |
| | 10000 |
| | 6804 |
| | — |
| | 3196 |

One figure in answer for each pair of figures in original number.

**Note.*—34 into 10, 0 times. Put 0 in answer and at left. Then bring down two more 0's. 340 into 1000, twice.

$\sqrt{\cdot 0004} = \sqrt{\cdot 0004}$

$= \cdot 0\ 2.$

$\sqrt{\cdot 004} = \sqrt{\cdot 004000}$

$= \cdot\ 0\ 6\ 3.$

## Proportion.

"Direct" and "Inverse" proportion.

Take Ohm's Law: The current in a circuit is directly proportional to the E.M.F. and inversely proportional to the resistance.

$I \propto E$. Direct proportion: as E increases I increases; as E decreases I decreases.

$I \propto \frac{1}{R}$. Inverse proportion: as R increases I decreases; as R decreases I increases.

Or, $I \propto \frac{E}{R}$.

## Circumference and Area of a Circle.

The diameter of any circle is contained a definite number of times in the circumference, $3\frac{1}{7}$ times approximately, or more accurately, 3·1416 times.

The letter "$\pi$" (pi) is used to represent the number of times. "$\pi$" is the ratio that the circumference bears to the diameter of any circle.

$$\frac{\text{Circumference}}{\text{Diameter}} = \pi,$$

or, Circumference $= \pi d$. (Put 2r, twice radius, for d.)

$= 2\pi r$.

If the diameter is **2·53″**, the circumference $= 2\cdot53 \times 3\frac{1}{7}$.

or $2\cdot53 \times 3\cdot1416$.

Both give 7·95″ to the nearest 2nd decimal place.

## Area.

The area of a circle is $\pi r^2$

$$= \pi \times \left(\frac{d}{2}\right)^2, \text{ (putting } \frac{d}{2} \text{ for r)},$$

$$= \frac{\pi}{4} \times d^2,$$

$$= \frac{11}{14} \times d^2 \text{ (when } \pi = 3\tfrac{1}{7}),$$

$$= \cdot7854d^2 \text{ (when } \pi = 3\cdot1416).$$

$\frac{11}{14}d^2$ is quite near enough for most purposes.

There is often confusion made in the use of $2\pi r$ and $\pi r^2$. Note that "r" will give linear inches, &c. (for circumference), and "$r^2$" will give square inches, &c. (for area).

## Circular Measure.

In the "sexagesimal" system of measuring angles the unit is the "degree."

60 seconds = 1 minute.
60 minutes = 1 degree.
90 degrees = 1 right angle.

This is the system adopted in elementary work generally, in Geometry and in Navigation, but in scientific work generally circular measure is more extensively used.

## The Unit in Circular Measure is the "Radian."

If a circle is drawn and the radius is marked off around the circumference and the points joined, a regular hexagon is formed, the sides being equal and each angle 120°. If the diagonals are drawn they pass through the centre, and each of the six angles at the centre is 60°.

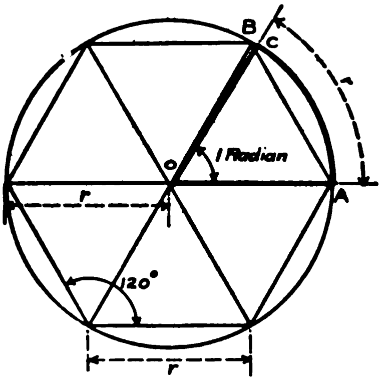


Fig. 1.

Now if the radius is laid off around the circumference from A (say, by a piece of thread equal in length to the radius) it will not reach B, but only as far as C. (Fig. 1.) AC is an arc of the circle equal in length to the radius. Join C to the centre O.

Then the angle AOC is an angle of 1 radian.

Thus, a radian is an angle at the centre of a circle subtended by (or opposite to) an arc equal in length to the radius.

For each time the radius is laid off around the circumference an angle of 1 radian will be marked out at the centre.

The radius is contained $2\pi$ times in the circumference, hence there are $2\pi$ radians in the 360° at the centre.

$$2\pi \text{ radians} = 360^\circ,$$
$$\pi \text{ radians} = 180^\circ,$$
$$1 \text{ radian} = \frac{180^\circ}{\pi} = 57\cdot3^\circ \text{ approx.}$$

To convert 83° to radians:

$$180^\circ = \pi \text{ radians};\ 83^\circ = \pi \times \frac{83}{180} = 1\cdot45 \text{ radians.}$$

To convert $2\cdot8$ radians to degrees:

$$\pi \text{ radians} = 180^\circ,\ 2\cdot8 \text{ radians} = 180^\circ \times \frac{2\cdot8}{\pi} = 180 \times 2\cdot8 \times \frac{7}{22} = 160\cdot4^\circ.$$

**Example.**

If a body revolves in a circular path of diameter 2 ft. and travels 1 ft. in $\frac{1}{100}$ second, find its angular velocity in radians per second, that is to say, if a line is drawn from the body to the centre of the circle, find how many radians this line sweeps through at the centre in 1 sec.

$$1 \text{ ft. in } \frac{1}{100} \text{ sec.} = 100 \text{ ft. per sec. (linear velocity).}$$

$$\text{Angle in radians} = \frac{\text{Arc of circle}}{\text{radius}},$$

$$= \frac{100 \text{ ft.}}{1 \text{ ft.}} = 100 \text{ radians.}$$

$$\text{Angular velocity} = 100 \text{ radians per sec.}$$

**Examples :—**

(8) The circumference of a circle is 9·2″ : find its radius. Ans. 1·46″.

(9) The area of a circle is 10·4 sq. ins. : find its diameter.

$$\left(\text{Thus } \frac{11}{14} d^2 = 10\cdot4,\ d^2 = 10\cdot4 \div \frac{11}{14}, \text{ then } d = \text{etc.}\right).$$

Ans. 3·64″.

(10) Convert 18° 24′ to radians, and 4·2 radians to degrees.

Ans. ·32 and 240° 33′.

(11) A wheel revolves at 1000 revs. per min. Find the angular velocity (radians per sec.) of any point on it. (Note that the linear velocity of points at different distances from its centre would not be the same.)

Ans. 104·8.

## ALGEBRA.

**Terms.**—Letters or symbols are used to represent quantities in a general way. We may look upon them, in working, as representing particular values, figures, or numbers.

"a + b" is an "expression" consisting of two "terms." If "a" represents the number 8, and "b" 5, then $a + b = 8 + 5 = 13$.

In the expression "3m," *i.e.*, 3 × m, 3 is the "co-efficient," *i.e.*, a multiplying number. Both "3" and "m" are "factors."

**Indices.**

In "$a^2$," 2 is the "index"; it indicates the power to which "a" is raised.

$a^4$ means a × a × a × a (not, as one frequently hears, "a" multiplied by itself four times, as there are only three multiplications).

$a^4$ is "unity (1) multiplied by 'a' 4 times," *i.e.*, 1 × a × a × a × a.

$a_1$, $a_2$, &c. The figures are not indices, but simply imply "a" number 1, "a" number 2, &c.

$$a^4 \times a^6 = a^{4+6} = a^{10}.$$

(Rule.—Add the indices — where the same letter occurs in each case.)

$$a^4 \times b^6 = a^4 b^6.$$

Two letters or terms placed side by side without any intervening sign indicate multiplication.

$$a^{12} \div a^7 = a^{12-7} = a^5.$$

(Rule.—Subtract the indices.)

From this we can find the meaning of $a^0$.

$$\left.\begin{array}{r} a^6 \div a^6 = a^{6-6} = a^0 \\ \text{but } a^6 \div a^6 \text{ also equals } 1. \end{array}\right\} \text{Thus } a^0 = 1.$$

Any letter or number raised to the power "0" = 1.

We can also see why $\frac{1}{a^3} = a^{-3}$.

$$\frac{1}{a^3} = \frac{a^0}{a^3} = a^{0-3} = a^{-3}.$$

### + and − Signs.

### Additions.

$\mathbf{3a - 2a + 6a - 5a = 2a.}$ ($+ 3a$ is understood for the first term.)

Rule.—Add together all the positive co-efficients and all the negative co-efficients, subtract them (7 from 9) and attach the sign of the greater.

$$\mathbf{-5b^2 + 2a^3 - 7b^2 - 5a^3}$$

$$= -3a^3 - 12b^2.$$

(The − sign must never be omitted.)

### Subtraction.

$$\begin{array}{r} \mathbf{-2a + 5b} \\ \mathbf{3a - 2b} \\ \hline \end{array}$$

Rule.—Change the signs of the expression to be subtracted and proceed as in addition.

The above becomes—

$$\begin{array}{r} -2a + 5b \\ -3a + 2b \\ \hline -5a + 7b. \end{array} \quad \text{Answer.}$$

### Multiplication.

The product of two quantities having like signs is positive.

$$(+\mathbf{a}) \times (+\mathbf{bc}) = +abc.$$

$$(-\mathbf{m}) \times (-\mathbf{m^2n}) = +m^3n.$$

The product of two quantities having unlike signs is negative.

$$(+\mathbf{a^2b}) \times (-\mathbf{3c}) = -3a^2bc.$$

(These two rules apply also to division.)

$$(\mathbf{4a - 2b}) \times \mathbf{3a^2}.$$

$$\begin{array}{l} 4a - 2b \\ 3a^2 \\ \hline 12a^3 - 6a^2b. \\ \hline \end{array}$$

Every term in the bracket has to be multiplied by $\mathbf{3a^2}$.

$$(\mathbf{3a + 2b}) \quad (\mathbf{4a + 5c}).$$

Both terms in the first bracket have to be multiplied by $+4a$ and by $+5c$.

$$(3a + 2b) \times 4a = 12a^2 + 8ab.$$

$$(3a + 2b) \times 5c = 15ac + 10bc.$$

Answer $12a^2 + 8ab + 15ac + 10bc$.

It may be noted that $(\mathbf{a + b})^2 = \mathbf{a^2 + 2ab + b^2}$. *Not* $\mathbf{a^2} + b^2$.

Thus, $\sqrt{a^2 + b^2}$ is not $a + b$,
and $\sqrt{3^2 + 4^2}$ is not $3 + 4 = 7$, but $\sqrt{9 + 16} = \sqrt{25} = 5$.
But $a^2 - b^2 = (a + b)(a - b)$.

That is, the sum of two numbers multiplied by their difference = the difference between their squares.

Thus, $4^2 - 3^2 = (4 + 3)(4 - 3) = 7 \times 1 = 7$.

**Division.**

$\frac{3a^2 - 6b^3}{-3}$. Both terms on top must be divided by − 3.

$$-3)\frac{3a^2 - 6b^3}{-1a^2 + 2b^3} \text{ or } 2b^3 - a^2.$$

We deal with the sign first, then the co-efficient, then the letter.

$$-ab)\frac{a^3b^2 - 2a^2b^4 + 3ab^2}{-a^2b + 2ab^3 - 3b} \; (-ab \text{ is of course } -1\,ab.)$$

**Brackets.**

An expression enclosed in a bracket must be treated as a whole; any operation must be performed alike on all the separate terms.

$$\begin{aligned} &3a\,(2b - c) - 2\,(ab - 3ac) \\ &= 6ab - 3ac - 2ab + 6ac \\ &= 4ab + 3ac. \end{aligned}$$

Simplify $\frac{2a}{3} + \frac{5a - 2b}{6} - \frac{2a - 5b}{9}$.

Proceed as in arithmetic. L.C.M. = 18. Note carefully that $\frac{5a - 2b}{6}$ and $\frac{2a - 5b}{9}$ are equivalent to bracketed expressions as will be seen in the working when $5a - 2b$ and $2a - 5b$ are multiplied by $+3$ and $-2$ respectively.

$$\begin{aligned} \text{The expression } &= \left\{12a + 3\,(5a - 2b) - 2\,(2a - 5b)\right\} \div 18 \\ &= \left\{12a + 15a - 6b - 4a + 10b\right\} \div 18 \\ &= \frac{23a + 4b}{18}. \end{aligned}$$

**The Simple Equation.**

The object is to find the value of a given letter which "satisfies" the equation

$$e.g., \; 3a = 9,$$

$$a = \frac{9}{3} = 3.$$

There is only one value of a, *i.e.*, 3, that will satisfy the equation.

An equation involving $a^2$ (2nd degree) is called a "quadratic equation,"

$$e.g., \; a^2 = 16,$$

$$a = \sqrt{16} = +4 \text{ or } -4, \text{ written } \pm 4.$$

There are two values of **a** which satisfy this equation, and such is the case with all quadratic equations.

Solve the equation $9a + 5 = 3a + 17$.

Arrange the terms containing **a** on one side and the plain figures on the other side.

The change must be made so that the left side will still remain equal to the right side.

That is, any term added to or subtracted from one side must be added to or subtracted from the other side.

We will subtract 5 from each side and 3a from each side, and get $9a - 3a = 17 - 5$.

Thus the method is, move 3a to the left side and change its sign; move + 5 to the right and change its sign.

$$\text{Then } 6a = 12$$

$$\text{and } a = 2.$$

$$\text{Solve } \frac{2m - 8}{5} = \frac{3m - 7}{7} + 3$$

$$\text{L.C.M. } 35.$$

$$7(2m - 8) = 5(3m - 7) + 3 \times 35,$$

$$14m - 56 = 15m - 35 + 105,$$

$$14m - 15m = 56 - 35 + 105,$$

$$- m = 126.$$

(Divide each side by − 1)

$$m = - 126.$$

$$\textbf{Solve } \frac{3x + 2}{5} = \frac{9x - 7}{3}.$$

We may proceed as above, or cross-multiply (having one fraction on each side).

$$3(3x + 2) = 5(9x - 7),$$

$$9x + 6 = 45x - 35,$$

$$9x - 45x = - 6 - 35,$$

$$- 36x = - 41$$

$$x = \frac{-41}{-36} = \frac{41}{36} = 1\frac{5}{36}.$$

**Examples.**

(12) Add together $2a - 3ab - 4bc$ and $2ab + 5c^2 - 6a$, and also subtract the latter from the former.

Ans. $- 4a - ab - 4bc + 5c^2$.
and $8a - 5ab - 4bc - 5c^2$.

(13) Multiply $5ab - 3m$ by $12ab - p$.

Ans. $60a^2b^2 - 5abp - 36abm + 3mp$.

(14) Solve the equations :—

(i) $3m - 2 = 12m + 6$. Ans. $-\frac{8}{9}$.

(ii) $\frac{3m}{3m + 2} = \frac{5}{6}$ Ans. $3\frac{1}{3}$.

(iii) $\frac{\cdot 2s}{\cdot 2 + s} = \cdot 15$ Ans. $\frac{3}{5}$.

## GRAPHS.

Graphs are straight lines or curves plotted on squared paper to show how one quantity is related to another (the one quantity depending on the other), and to show how one varies as the other varies.

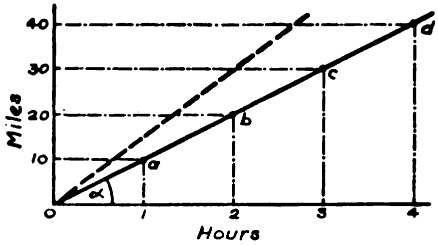


FIG. 2.

A cyclist travels at 10 m.p.h. Draw a distance-time graph.

The method of "plotting" will be obvious from the diagram (full line). The plotted points are a, b, c, d. The graph shows how the distance travelled increases as the time increases.

We can take from it intermediate readings and obtain distances travelled corresponding to certain times, or the times to travel certain distances. In this case the distance travelled is proportional to the time, and in this, and similar cases, the resulting graph is a straight line.

This indicates that the **rate** at which the distance increases is uniform.

The slope (or steepness) of a curve (all graphs, straight or not, are called "curves") indicates the **rate** at which one quantity is changing with respect to another.

Thus the slope of the curve indicates whether the **rate of change** is great or small.

The slope is measured by the angle ($a$) that the graph makes with the horizontal at the point under consideration.

In the above example,

$$\text{Rate of change (of distance to time)} = \frac{10 \text{ miles}}{1 \text{ hour}} \text{ or 10 miles per hour.}$$

This is how the slope of the curve is measured.

Had the speed been 15 m.p.h. the distance-time graph (shown dotted) would have been steeper, indicating that the change of distance per unit time is greater. The graph makes a greater angle with the horizontal, *i.e.*, it has greater slope.

Draw a graph representing a steady current of 10 amps. flowing in a circuit (Fig. 3, dotted curve).

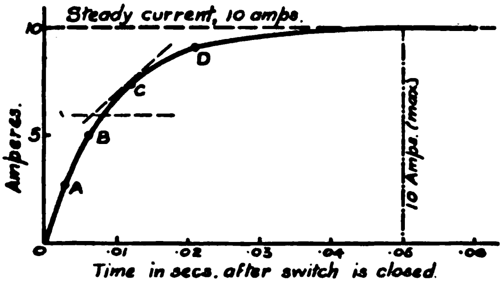


FIG. 3.

This straight line has no slope (being horizontal), *i.e.*, there is no rate of change—the current is not changing in value.

Next, consider a current-time graph to represent the current growing from zero to 10 amps. in ·05 second when the switch is closed. (*See* Fig. 3.)

The portion of the curve OAB is very steep, *i.e.*, the current is growing very rapidly—or the rate of change (or increase) of current is great.

At C the slope is not so great, and at D is still less. Onwards from about C the current is growing at a much slower rate.

The slope is indicated by a "tangent" (*i.e.*, a line drawn to touch the curve at a point) at any point on the curve. Such a tangent is shown at C. It makes a certain angle with the horizontal. One drawn at D will make a much smaller angle with the horizontal. A small angle indicates a small rate of change.

At any point in the portion OAB, any tangent is practically in line with the curve, and makes a big angle with the horizontal, *i.e.*, the rate of increase of current is great.

The "Crystal" characteristic curves (Chapter IX.) indicate this idea of steepness and rate of change very clearly. After the critical point is reached there is a very rapid change of current for a small increase of voltage, *i.e.*, when the curve becomes steep.

## LOGARITHMS. (*See* p. 532.)

By logarithms we are enabled to perform multiplication, division, involution (*e.g.*, $1 \cdot 84^3$) and evolution (*e.g.*, $\sqrt[3]{1 \cdot 84}$) very simply and rapidly.

The system of "Common Logarithms" will be described. In this system the logarithms are made out to the "base" 10.

$$100 = 10^2$$

100 is termed the "number,"
10 is the "base,"
2 is the "logarithm."

Thus $\log_{10}$ 100 (log. of 100 to the base 10) = 2.

| | No. | Log. |
|---|---|---|
| $10^2$ | 1000 | 3 |
| $10^2$ | 100 | 2 |
| $10^1$ | 10 | 1 |
| $10^0$ | 1 | 0 |
| $10^{-1} \left(\frac{1}{10}\right)$ | ·1 | –1 |
| $10^{-2} \left(\frac{1}{10^2}\right)$ | ·01 | –2 |
| $10^{-3} \left(\frac{1}{10^3}\right)$ | ·001 | –3 |

From this table it will be seen that the logs. of numbers greater than 1 are positive, and logs. of numbers less than 1 are negative. Log. 1 = 0.

Take the number 387. It lies between 100 and 1,000. Hence its log. lies between 2 and 3. The log. is, in fact, 2·5877.

$$\text{Log}_{10}\ 387 = 2 \cdot 5877.$$

The whole number part (2) is the "**Characteristic.**"

The decimal part (·5877) is the "**Mantissa.**"

The **Mantissa** is found from a table of logs, as follows (*see* table of four figure logs, p. 532).

The first two figures of the number are in the column at the left.

The third figure of the number appears at the head of one of the next ten columns.

The fourth figure appears at the head of one of the last nine columns (the difference columns).

To find log 345·6 (mantissa only):

Start with "34" in left-hand column, follow along this line until you come under "5"—you will find 5378. Then follow along to the difference column under "6"—you will find "8"; this is added to 5378 and 5386 is obtained.

Log 345·6 = ·5386 (mantissa only).

Every mantissa in the body of the table is understood to have a decimal point before it and is always positive.

Never mind the decimal point in the number in finding the mantissa.

### Rules for Characteristics of Numbers greater than 1.

The characteristic is found by this rule: "The characteristic of the log of a number greater than 1 is positive and is **one less** than the number of figures in the whole number part (or integral part) of the number."

Thus, the number 345·6 has three figures in the integral part, hence the characteristic of its log. is 2.

Log 345·6 = 2·5386.
Log 345600 = 5·5386.
Log 3·456 = 0·5386.

Note that the same sequence of figures in the number, as above, gives the same mantissa, but the characteristic must be separately determined from the above rule. The tables do not give us characteristics.

In the case of numbers less than 1, whose logs. are negative, we need another rule.

Refer to the table given above. Take the number ·08. It lies between ·01 and ·1, so that its log. lies between − 1 and − 2. It is in fact − 1·0969. But it is never given in the tables in this form. A mantissa is always positive in the tables.

It is converted thus—

$$\begin{array}{lll} -1 \text{ and } & -\,0\cdot0969 & \\ -1 & +\,1 & \text{(making no ultimate change)} \\ \hline -2 \text{ and } & 0\cdot9031 & \\ \quad i.e., & \bar{2}\cdot9031 & \text{(negative characteristic,} \\ & & \quad\text{positive mantissa).} \end{array}$$

This is done both for convenience in use and in printing. Look up the mantissa as before, ignoring the decimal point in the number, *i.e.*, look up 80 at the left—we find ·9031.

### Rule for Characteristics of Numbers less than 1.

The characteristic of the log. of a number less than 1 is negative, and is **one more** than the number of cyphers immediately after the decimal point of the number.

Number = ·08, one cypher immediately after the decimal point, hence the characteristic is −2.

$$\log \cdot08 = \bar{2}\cdot9031.$$

Find log ·6308. Mantissa = ·7998.

Characteristic : no cyphers immediately after decimal point, $0 + 1 = 1$, *i.e.*, $\bar{1}$.

$$\log \cdot6308 = \bar{1}\cdot7998.$$

### Multiplication.

The **principle** is : $10^2 \times 10^3 = 10^{2+3} = 10^5$. 2, 3 and 5 are logs. The logs. of the numbers to be multiplied are added to give the log. of the answer.

Ex. : **2·06 × 93·87.**

$$\begin{array}{rl} \log\ 2\cdot06 = & 0\cdot3139 \\ \log\ 93\cdot87 = & 1\cdot9725 \\ \hline \text{(add)} & 2\cdot2864 = \text{log. of answer.} \end{array}$$

### De-logarising.

We now go to the table of "Anti-logarithms" (p. **534**) to find the number corresponding to the log. (**2·2864**).

We look up the mantissa only in the table just as we look up the number in the table of logarithms—

·28 at the left, then 6, then 4 in the difference columns.

Thus we find 1932 + 2 = 1934.

The log. (2·2864) is positive, hence the number is greater than 1. We have now to find how many figures there are in the integral part of the number.

The characteristic (2) indicates three figures in the integral part.

Hence the number of 193·4.

Thus, 2·06 × 93·87 = 193·4.

### Division.

The **principle** is : $10^5 \div 10^3 = 10^2$, *i.e.*, the logs. of the numbers to be divided are subtracted to give the log. of the answer.

Ex. **·0693 ÷ 37·48.**

$$\begin{array}{rl} \log \cdot 0693 = & \bar{2}\cdot 8407 \\ \log 37\cdot 48 = & 1\cdot 5738 \\ \hline \text{(subtract)} & \bar{3}\cdot 2669 = \text{log. of answer.} \end{array}$$

When the characteristics are subtracted, remember the rule for subtraction—change sign of bottom number and proceed as in addition.

Mantissa ·2669 from anti-logs. gives 1849.

Characteristic $\bar{3}$ indicated **two** cyphers immediately after decimal point.

Hence number required is ·001849.

### Powers.

Principle : $(10^2)^3 = 10^2 \times 10^2 \times 10^2 = 10^{2 \times 3} = 10^6$, *i.e.*, the log. (2) of the number is multiplied by the index (3) of the power to which the number has to be raised.

Ex. : **$1\cdot 008^3$.**

$\log 1\cdot 008^3 = 3 \times \log 1\cdot 008 = 0\cdot 0033 \times 3 = 0\cdot 0099.$

Mantissa ·0099 gives 1023.

Characteristic 0 indicates one figure in integral part of number.

Answer : **1·023.**

Note this example especially :—

**$\cdot 963^5$.**

$$\begin{array}{rr} 5 \times \log \cdot 963 = & \bar{1}\cdot 9836 \\ & 5 \\ \hline & \bar{1}\cdot 9180 \end{array}$$

Mantissa ·9180 gives 8279.

Characteristic $\bar{1}$ indicates one more than the number of cyphers immediately after the decimal point, *i.e.*, no cyphers.

Answer : ·8279.

### Roots.

Principle : $\sqrt[3]{10^4} = (10^4)^{\frac{1}{3}} = 10^{4 \times \frac{1}{3}} = 10^{4 \div 3}$,

*i.e.*, the log. (4) of the number is divided by the number indicating the root (3).

Ex. : **$\sqrt[3]{10\cdot 36}$.**

$$\begin{array}{rl} \log \sqrt[3]{10\cdot 36} = & 3\underline{)1\cdot 0153} \\ & \phantom{3)}\cdot 3384 \qquad \text{(divide only to 4 places)} \\ = & \text{log. of number } 2\cdot 18. \\ \sqrt[3]{10\cdot 36} = & 2\cdot 18. \end{array}$$

Ex. **$\sqrt[5]{\cdot 0068}$.**

$\log \sqrt[5]{\cdot 0068} = \bar{3}\cdot 8325 \div 5.$

We cannot say 5 into 3·8 = ·7 as the 3 is negative and the 8 positive. We **increase** the characteristic until 5 will divide exactly into it, *i.e.*, add −2 and make it − 5. To balance this we add + 2 to the mantissa.

$$\begin{array}{rl} \text{Thus we have :} & \bar{3} + 0\cdot 8325 \\ & \underline{\bar{2} + 2\phantom{\cdot 8325}} \\ 5) & \bar{5} + 2\cdot 8325 \\ & \bar{1} + 0\cdot 5665 \text{ or } \bar{1}\cdot 5665 \\ & \qquad = \text{log of } \cdot 3685. \\ & \sqrt[5]{\cdot 0068} = \mathbf{\cdot 3685}. \end{array}$$

**Further Examples :**

$$f = \frac{4\cdot 8 \times 10^6}{\sqrt{LC}} = \frac{4\cdot 8 \times 10^6.}{\sqrt{109\cdot 2 \times \cdot 29}} \text{ (say).}$$

Subtract log. of denominator from log. of numerator.

$$\begin{array}{lll} \text{Numerator.} & & \text{Denominator.} \\ \log 4\cdot 8 = 0\cdot 6812 & & \log 109\cdot 2 = 2\cdot 0382 \\ \log 10^6 \ = 6 & & \log \cdot 29 \ \ = \bar{1}\cdot 4624 \\ \text{(add)} \quad 6\cdot 6812 & \text{(add and divide by 2)} & 2)\underline{1\cdot 5006} \\ & & \quad \cdot 7503 \end{array}$$

$$\begin{array}{l} \text{log. of numerator} \quad = 6\cdot 6812 \\ \text{log. of denominator} = \ \ \underline{\cdot 7503} \\ \qquad \text{(subtract)} \quad 5\cdot 9309 = \text{log of } 852900. \\ \qquad\qquad f = 852900. \end{array}$$

$$\lambda = 20\pi\sqrt{LC} = 20\pi\sqrt{326 \times \cdot 18} \text{ (say) metres.}$$

$$\begin{array}{l} \log 326 = 2\cdot 5132 \\ \log \cdot 18 = \underline{\bar{1}\cdot 2553} \\ \qquad 2)\underline{1\cdot 7685} \\ \qquad\quad \left.\begin{array}{r} \cdot 8842 \\ \log 20 = 1\cdot 3010 \\ \log \pi = \cdot 4971 \end{array}\right\} \text{Add.} \\ \qquad\quad 2\cdot 6823 = \text{log of } 481\cdot 1. \\ \qquad \lambda = 481 \text{ metres.} \end{array}$$

Care must be taken when + and − signs occur in a question. Actual numbers, but *not* the logarithms, must be added and subtracted.

Ex. $3\cdot 806^2 + 19\cdot 23^2$.

Method: work out $3\cdot 806^2$ separately, using logs.: then $19\cdot 23^2$ separately. Add the resulting numbers.

Ex. $\sqrt{3\cdot 806^2 + 19\cdot 23^2}$.

Obtain the sum of the squares, as above : then find the square root of the result, by logs.

Examples :—

| | | |
|---|---|---|
| (15) | $3\cdot 298^2 \times \cdot 00263$. | Ans. ·02862. |
| (16) | $\sqrt[3]{9\cdot 12^2 \times 10\cdot 2}$. | Ans. 9·466. |
| (17) | $\sqrt{9\cdot 12^2 + 10\cdot 2}$. | Ans. 9·663. |
| (18) | $\sqrt{89\cdot 26^2 - 70\cdot 02^2}$. | Ans. 55·38. |
| (19) | $\dfrac{4\cdot 8 \times 10^6}{\sqrt{2\cdot 07 \times 106}}$. | Ans. 32410. |

Practice makes perfect.

## TRIGONOMETRY.

This subject deals primarily with the relationship between the sides and angles of a triangle.

Consider an angle $a$. (Small Greek letters are generally placed in angles to name them.)

We will consider the " ratios " of the angle $a$ (the angle of reference for the time being).

Draw a perpendicular to one of the lines enclosing the angle so as to form a right angle triangle (Fig. 4). The longest side, that opposite the largest angle (90°), is called the "Hypotenuse."

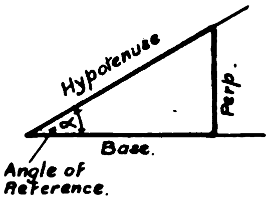


FIG. 4.

The side opposite the angle of reference is the "Perpendicular."

The remaining side is the "Base."

The "perpendicular" in Fig. 4 is not so named because it is drawn as a vertical line; nor is the "base" so named because it is drawn as a horizontal line.

Draw a right-angled triangle in another position.

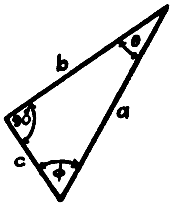


FIG. 5.

If $\theta$ is the angle of reference, then "a" is the hypotenuse, "c" the perpendicular, and "b" the base.

If $\phi$ is the angle of reference, then "a" is still the hypotenuse, "b" the perpendicular, and "c" the base.

There are six principal ratios; the first three are the most important for our purpose.

The sine of the angle $a$ (*see* Fig. 4) is the ratio that the perpendicular bears to the hypotenuse.

$$\text{Sine } a \ (\sin a) = \frac{\text{perpendicular}}{\text{hypotenuse}}$$

$$\text{Cosine } a \ (\cos a) = \frac{\text{base}}{\text{hypotenuse}}$$

$$\text{Tangent } a \ (\tan a) = \frac{\text{perpendicular}}{\text{base}}.$$

The other three are the reciprocals of these. (The reciprocal of a number is unity (1) divided by the number. Thus the reciprocal of $\frac{2}{3} = 1 \div \frac{2}{3} = \frac{3}{2}$.)

$$\text{Cosecant } a \ (\text{cosec } a) = \text{reciprocal of } \sin a = \frac{\text{H}}{\text{P}}$$

$$\text{Secant } a \ (\sec a) = \quad ,, \quad ,, \cos a = \frac{\text{H}}{\text{B}}$$

$$\text{Cotangent } (\cot a) = \quad ,, \quad ,, \tan a = \frac{\text{B}}{\text{P}}.$$

In a right-angled triangle the square on the hypotenuse is equal to the sum of the squares on the other two sides.

$$H^2 = P^2 + B^2.$$

To find the length of the hypotenuse when P = 5 and B = 12—

$$H^2 = 5^2 + 12^2 = 169$$

$$H = \sqrt{169} = 13.$$

To find the length of one of the shorter sides (say P) when H = 10 and B = 6—

$$H^2 = P^2 + B^2,$$

$$10^2 = P^2 + 6^2,$$

$$\text{or, directly, } P^2 = 10^2 - 6^2 = 64$$

$$\text{and } P = 8.$$

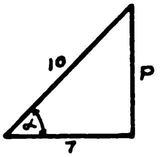


FIG. 6.

If cos $a$ = ·7 find the value of sin $a$ and tan $a$.

$$\text{Cos } a = \frac{7}{10} = \frac{\text{base}}{\text{hypotenuse}}.$$

The length of the perpendicular must be found.

$$P^2 = 10^2 - 7^2 = 51,$$

$$P = \sqrt{51} = 7 \cdot 14.$$

$$\text{Sin } a = \frac{P}{H} = \frac{7 \cdot 14}{10} = \cdot 714.$$

$$\text{Tan } a = \frac{P}{B} = \frac{7 \cdot 14}{7} = 1 \cdot 02.$$

**Sines.**

The perpendicular of a right-angled triangle is always less than the hypotenuse, hence the sine of an angle cannot be greater than 1 or less than 0, numerically.

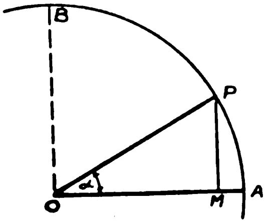


FIG. 7.

OA is a fixed line and OP a line of equal length free to revolve about O. As OP revolves it marks out an angle $a$ at O.

$$\text{Sin } a = \frac{PM}{OP}.$$

As OP approaches OA, the perpendicular PM becomes shorter and shorter. When OP reaches OA, and $a$ becomes 0°, then PM becomes 0.

$$\text{Thus, sin } 0^\circ = \frac{0}{OP} = 0.$$

As OP approaches OB, the perpendicular becomes longer and longer. When OP reaches OB, and $a$ becomes 90°, then PM becomes equal to OB (or OP).

$$\text{Thus, } \sin 90° = 1.$$

As the angle increases from 0° to 90° its sine increases from 0 to 1.

**Cosines.**

$$\text{Cos } 0° = 1, \text{ and } \cos 90° = 0.$$

The reader should reason this out in a similar manner from Fig. 7.

As the angle increases from 0° to 90° its cosine decreases from 1 to 0.

**Tangents.**

$$\text{Tan } 0° = 0, \tan 45° = 1, \tan 90° = \infty.$$

When OP reaches OB the base OM becomes zero, and tan 90° = $\frac{\text{Perpendicular}}{\text{Base}} = \frac{\text{OB}}{0}$ = infinity ($\infty$).

These results will be seen in the table of trigonometrical ratios (p. 536).

For angles from 0° to 45° (on the left) use the headlines at top of the columns. For angles from 45° to 90° use the wording at the bottom of the columns.

It will be noticed that the same value is given in the table for sin 20° (say) and cos 70°, *i.e.*, sin 20° = cos 70°.

The sin of an angle = the cosine of its complement (*i.e.*, its difference from 90°).

$$\text{Or, } \sin a = \cos (90° - a).$$
$$\text{Also } \tan a = \cot (90° - a).$$

**Angles greater than 90°.**

In geometry angles are limited in magnitude to 180°, but in trigonometry there is no limit to their magnitude, and, in addition, they may be positive or negative.

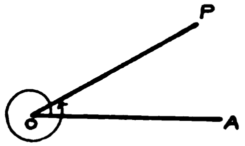


FIG. 8.

Let the line OP start at OA and revolve in an anti-clockwise direction. It marks out positive angles as it revolves (and negative angles if it revolves from OA in a clockwise direction).

In a clockwise revolution it marks out 360° or $2\pi$ radians, in two revolutions 720°, and so on. In Fig. 8 OP has traced out an angle of 390°.

It has been shown that, for angles between 0° and 90°, the sines, cosines and tangents lie between 0 and 1, 1 and 0, and 0 and $\infty$ respectively. We have now to see how these ratios vary as the angle increases to 360°.

Consider any angle in each of the four "quadrants" (0° to 90°, 90° to 180°, 180° to 270°, 270° to 360°).

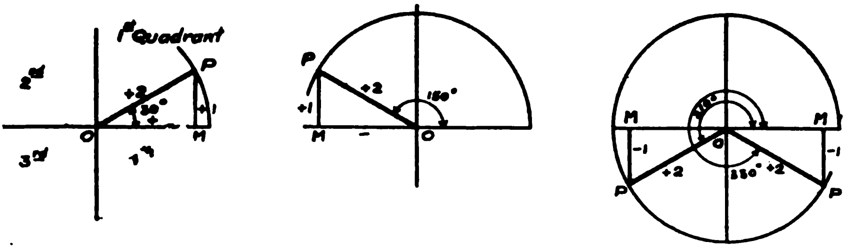
The revolving line OP is always positive. Perpendiculars (PM) above the horizontal line are positive, and below negative.

Bases (OM) to the right of O are positive and to the left negative.

Thus, in the first quadrant, OP, PM, OM are all positive, and the sines, cosines, or tangents of angles from 0° to 90° are positive. We will consider sines only. The reader may argue the cases of cosines and tangents for himself.

$$\text{1st quadrant: } \sin 30^\circ = \frac{PM}{OP} = \frac{+1}{+2} = +\frac{1}{2} \text{ (Fig. 9}(a)\text{ ).}$$

$$\text{2nd quadrant: } \sin 150^\circ = \frac{+1}{+2} = +\frac{1}{2} \text{ (Fig. 9 }(b)\text{ ).}$$



(a) (b) (c)

FIG. 9.

The perpendicular and hypotenuse (1 and 2) are the same lengths as for 30° and both are positive.

$$\text{Hence } \sin 150^\circ = \sin 30^\circ = +\frac{1}{2}.$$

Similarly the sines of all angles between 90° and 180° are positive and range from 1 to 0.

3rd and 4th quadrants : $\sin 210^\circ$ (Fig. 9 (c) ) $= \frac{-1}{+2} = -\frac{1}{2}$ *i.e.* $\sin 210^\circ$ $=$ sin 30° in magnitude, but is negative.

$\sin 330^\circ = \frac{-1}{+2} = -\frac{1}{2}$, *i.e.*, sin 330° = sin 30° in magnitude, but is negative.

The sines of all angles from 180° to 360° are negative; for angles from 180° to 270° they range from 0 to − 1, and for angles from 270° to 360° they range from −1 to 0.

We have traced out a complete cycle of values for sines, *i.e.*, from 0 to 1 and 1 to 0, 0 to − 1, and − 1 to 0 again.

It will be seen from the above cases why sines, &c., of angles from 0° 90° only need be printed in a table. The ratios (values and signs) can be obtained from a thumb-nail sketch of the angle, as shown above.

Thus, cos 260° = cos (260° − 180°) = cos 80° = ·1736, but it is negative. Cos 260° = − 0·1736.

**Examples :—**

(20) Sin $\theta$ = ·73. Calculate the values of cos $\theta$ and tan $\theta$. Then, again using sin $\theta$ = ·73, find the value of the angle $\theta$ from the Tables : then look up cos $\theta$ and tan $\theta$ to check the results obtained above. (The results will be approximate, as $\theta$ can be read only to the nearest degree.)

Ans. : ·684, 1·07 ; 47°.

(21) Find the values of tan 103°, cos 203°, sin 303°.

Ans. : − 4·33, −·92, −·84.

## MECHANICS.

There are so many mechanical analogies used in connection with the explanation of electrical phenomena, that it is considered of value to include here a few of the elementary principles of mechanics.

There are two main divisions of the subject :—

Statics (dealing with bodies kept at rest by forces), and
Dynamics (dealing with moving bodies).

## VECTOR AND SCALAR QUANTITIES.

A vector quantity is one which has magnitude and direction. It can be represented in magnitude and direction by a straight line.

Examples : A force or an E.M.F., a velocity or a current.

We have also "Revolving Vectors," and have already made use of them. They are used to indicate in a diagram the relative phase between two or more directed quantities—such as an E.M.F. and current.

A scalar quantity is one which has magnitude but not direction. Its magnitude can be represented by a straight line. Examples : Mass, Time, Resistance.

**Parallelogram of Forces** (or of Velocities).

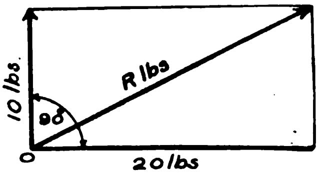


FIG. 10.

Two forces of 10 lbs. and 20 lbs. (represented in Fig. 10 by vectors) act at an angle of 90° at a point O. Their resultant (*i.e.* a force which will produce the same effect as the two together) is found by completing the parallelogram or rectangle about them, and drawing the diagonal through O. Then, the diagonal (R) will represent their resultant in magnitude and direction.

$$\text{In this case, } R^2 = 10^2 + 20^2 = 500,$$

$$\text{and } R = \sqrt{500} = 22 \cdot 36 \text{ lbs.}$$

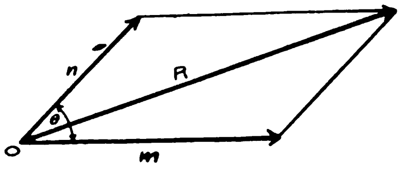


FIG. 11.

Two forces, m and n (Fig. 11), act at the point O at an angle $\theta$ ($\theta$ representing any angle between 0° and 180°).

Then $R^2 = m^2 + n^2 + 2mn \cos \theta$.

If the body, on which the two forces act, were free to move, it would move off in the direction of the resultant force.

We have already had a number of applications of this principle, *e.g.*, in Chap. V., when we found the resultant or applied E.M.F. of (1) the E.M.F. required to balance the E.M.F. of self-induction, and (2) the E.M.F. to drive the current through the ohmic resistance, (1) and (2) being 90° out of phase.

The same principle applies to velocities (or currents). There is the case of two circuits in parallel across the A.C. mains—one containing resistance only and its current in phase with the pressure, and the other capacity only and its current leading 90° on the pressure.

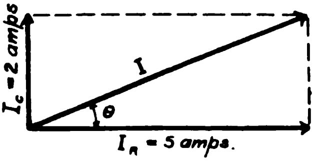


FIG. 12.

Resultant or main current $I = \sqrt{5^2 + 2^2} = 5\cdot385$ amps. (Fig. 12).

Tan $\theta = \frac{2}{5} = \cdot4$, whence $\theta = 22°$, *i.e.*, the main current leads by 22° on the pressure.

**Resolution of Forces.**

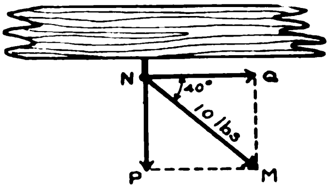


FIG. 13.

A force of 10 lbs. (NM) pulls on a nail in a beam at an angle of 40° to the horizontal. It tends partly to pull the nail out and partly to bend it to the side. It is required to find the vertical and the horizontal force.

Complete a rectangular about MN.

Then NQ and NP represent the two required forces.

They are the two "components" of the original force (NM), and we have "resolved" the forces NM into two components.

$$NQ = NM \times \cos 40° = 10 \times \cdot766 = 7\cdot66 \text{ lbs.}$$
$$NP = NM \times \sin 40° = 10 \times \cdot643 = 6\cdot43 \text{ lbs.}$$

An application of this principle occurs in considering the calculation of power in an A.C. circuit.

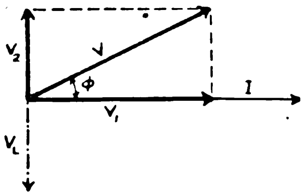


FIG. 14.

Let the current (I) lag by the angle $\phi$ on the pressure (V) due to the presence of inductance.

Resolve V into two components, one in phase with the current ($V_1$) and one 90° out of phase with the current ($V_2$).

$V_1 = V \cos \phi$ and contributes to the power in the circuit.

$V_2 = V \sin \phi$ and does not, but is employed in balancing the E.M.F. of self-induction ($V_L$).

Power $= V_1 I = VI \cos \phi$ watts (V and I being R.M.S. values).

**Moments.**

The moment of a force is the twisting effect it exerts about a fixed point or axis.

When we turn a clock key, or use a lever of any kind, we apply a force at a certain distance from a fixed point or axis, and so employ a certain "leverage." A twisting effect is exerted which depends upon (1) the magnitude of the force (P lbs.), and (2) the distance from the axis (r ft.).

Moment of each force (*see* Fig. 15) = P lbs. × r ft.
Pr. ft.—lbs.
(or " lb.—ft.").

We met the same idea in the torque of a motor, *i.e.*, the twisting effect exerted by the F.M. poles on the armature. It is measured by—

Total pull on all the armature conductors (P lbs.) × radius of arm (r ft.).

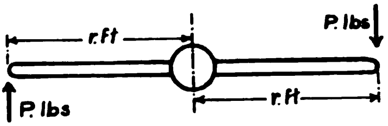


FIG. 15.

## Mass and Inertia.

**Mass** is the amount of " matter " in a body. (By " matter " we understand that of which a body is composed, which occupies space, and can be detected by the human senses.)

The unit of measurement in the F.P.S. (ft.—lb.—sec.) system is the pound (lb.) and, in the C.G.S. (cm.—gramme.—sec.) system, the gramme (gm.).

**Inertia** is the property possessed by a body of opposing any change in its state of rest or uniform motion in a straight line.

That is, to get a body into motion, to bring it to rest, or to change its speed, an expenditure of energy is required to overcome its inertia.

## Weight.

The weight of a body is the force with which it is attracted towards the centre of the earth.

The units are the pound or the gramme.

All bodies attract one another. This explains the cohesion between the particles or molecules of a body. The force of attraction between two bodies depends upon their masses and their distance apart.

$$\text{Attractive force} \propto \frac{m_1 \times m_2}{d_2}.$$

The greater their masses ($m_1$ and $m_2$) and the closer they are together (distance apart " d ") the greater will be the force of attraction.

Thus, a certain body will be attracted to the earth by a force depending upon the mass of the earth, the mass of the body, and the distance between the centre of the earth and of the body. It will accordingly have slightly less " weight " when in the region of the equator than when in a region nearer either pole, as it is then farther from the centre of the earth. The weight of a body varies according to its position on the earth's surface. But the mass of a given body is constant.

## Acceleration.

When a body falls freely and is not appreciably impeded, as a feather or a sheet of paper, by air resistance, it has a uniform acceleration.

This acceleration is the same for all bodies under the same conditions at a given place. At places on the earth's surface nearer the centre (*i.e.*, the higher latitudes) the acceleration will be greater. In London it is 32·2 feet per sec. per sec. We work with 32 for ordinary purposes in this country. That is, the velocity of the body increases by 32 ft. per sec. at the end of every second.

After 1 sec. from the commencement of a freely falling body acquires a velocity of 32 ft. per sec., at the end of the next sec. 64 ft. per sec., at the end of the third sec. 96 ft. per sec., and so on.

"g" denotes generally the acceleration of a freely falling body.

During the first sec. its **mean** velocity is $\frac{0 + 32}{2} = 16$ ft. per sec. and it will travel 16 ft.; in the next sec. its mean velocity will be $\frac{32 + 64}{2} = 48$ ft. per sec. and it will travel 48 ft.; and so on.

A body has a mass of 1 lb. It is pulled vertically downwards with a force of 1 lb. (or 1 lb. weight), and it acquires an acceleration of 32 ft. per sec. per sec., *i.e.*, the force of 1 lb. acting on a mass of 1 lb. produces an acceleration of 32 ft. per sec. per sec.

Hence, a force of $\frac{1}{32}$ lb. acting on a mass of 1 lb. produces an acceleration of 1 ft. per sec. per sec.

This force of $\frac{1}{32}\left(\text{or } \frac{1}{g}\right)$ lb. is called a "poundal," *i.e.*, the force which produces unit acceleration in unit mass (F.P.S. system).

$$P \propto ma \begin{cases} P = \text{force in poundals.} \\ m = \text{mass in lbs.} \\ a = \text{accel. in ft. per sec. per sec.} \end{cases}$$

or $P \text{ (lbs.)} = \frac{ma}{g}$.

In the C.G.S. system, similarly, a force of $\frac{\text{“}1\text{”}}{g}$ of a gramme will produce unit acceleration (1 cm. per sec. per sec.) in unit mass (1 gramme).

This force is called the "dyne."

As "g" = 981 cms. per sec. per sec. (32·2 ft. per sec. per sec.)—

$$1 \text{ dyne} = \frac{1}{981} \text{ gramme.}$$

The **dyne** is a minutely small force, being roughly only $\frac{1}{445000}$ lb.

A truck of mass 200 lbs. has to be moved from rest with acceleration of 2 ft. per sec. per sec. until it acquires a velocity of 10 ft. per sec. against a constant friction of 40 lbs. Find the force required.

(1) Find the force to produce an acceleration of 2 ft. per sec. per sec. (*i.e.*, to overcome inertia at this rate):—

$$P = \frac{ma}{g} \text{ lbs.} = \frac{200 \times 2}{32} = 12\tfrac{1}{2} \text{ lbs.}$$

(2) A force of 40 lbs. is constantly required to overcome the friction.

Total force = 52½ lbs.

But as soon as a velocity of 10 ft. per sec. is reached (after 5 seconds) a force of only 40 lbs. will be necessary to maintain this speed steadily.

We compare current (amps., or coulombs per sec., or electrons per sec.) with velocity (ft. per sec.).

Rate of change of current (amps. per sec. or coulombs per sec. per sec.) is compared with acceleration (ft. per sec. per sec.).

We may liken the above example to the conditions when a current is growing from zero to its maximum value in a D.C. circuit.

The current cannot instantly reach its maximum value on account of the inductance or electrical inertia of the circuit. There is a period of "acceleration." During the time the current is growing, *i.e.*, during which the E.M.F. of self-induction is in existence, a portion of the applied voltage is employed in overcoming this counter E.M.F. The other portion drives the current through the ohmic resistance (comparable with friction).

When the current reaches its maximum and becomes steady, the applied voltage has only the resistance to overcome.

### Momentum.

The momentum of a body is a property depending upon its mass and its velocity. It is measured by the product of mass and velocity. When we refer to the " way " on a boat we mean its momentum.

### Work.

Work, in a mechanical sense, is done when a force moves a body through a certain distance. It is measured in " ft.-lbs." A force of 10 lbs. moves a body to a distance of 6 ft. and it does 10 lbs. × 6 ft. or 60 ft.-lbs. of work.

In the C.G.S. system the unit is the " Erg."

An " Erg " is the amount of work done by a force of one dyne acting for a distance of 1 cm.

$10^7$ ergs = 1 joule (the " practical " unit).

### Energy.

Energy is the ability of a body to do work by virtue of its position (" potential energy ") or its motion (" kinetic energy ").

It is measured in work units—ft.-lbs. or ergs.

If a mass of 20 lbs. has to be raised a distance of 5 ft. vertically, a force of 20 lbs. is required, and the work done in raising it will be 100 ft.-lbs. This represents the amount of energy that will now be stored in the body due its position.

After the body has returned to its original level it will have expended this amount of energy in some form or other.

Before a body can acquire a certain velocity a certain amount of energy must be expended in overcoming its inertia. This amount of energy will become stored up in the moving body and is now termed kinetic energy. (The amount of energy expended in overcoming friction will have been wasted, or, rather, lost to us, in the form of heat.).

After the body had been brought to rest again it will have expended this amount of energy required to overcome its inertia.

The energy stored up in a body due to its position (potential energy) may be compared with the energy stored up in a condenser by forcing a certain charge (or quantity of electricity) into it at a certain pressure, *i.e.*, Q coulombs × E volts = QE joules (where E is the mean charging voltage).

The energy stored up in a body due to its motion may be compared with the energy stored in the circuit, *i.e.*, in the magnetic field, when the current has been established.

This is measured by $\frac{1}{2}LI^2$ joules. $\left\{\begin{array}{l}L \text{ henries,}\\ I \text{ amps.}\end{array}\right.$

This should be compared with the kinetic energy of a body of mass m lbs. and velocity v ft. per sec.,

*i.e.*, $\frac{1}{2}mv^2$ ft.-poundals,

or $\frac{mv^2}{2g}$ ft.-lbs.

" m " corresponds to " L " and " v " to " I."

" L " is the inductance or the electrical inertia of the circuit. " m " is the mass of the body, and the inertia of a body depends upon its mass.

The energy expended in the circuit in causing the current to grow to its full value (*i.e.*, in causing the acceleration of the electrons) is not wasted;

It is recoverable when the current falls again. On the other hand, the energy expended in heat in overcoming the resistance as the current is growing is not recoverable (unless means are adopted to utilise it.).

## Power.

Power is the rate of doing work, or the rate of producing or expending energy.

The unit is the "Horse Power," which is a rate of working of 550 ft.-lbs. per sec., or 33,000 ft.-lbs. per min.

In the C.G.S. system, it is the "Watt," which is a rate of working of "1 joule per sec."

746 Watts = 1 H.P.
1 H.P. = 550 ft.-lbs. per sec.,
(say) 55 lbs. × 10 ft. per sec.

or, generally: Power = Force × Velocity.

In electrical units: Watts = Volts × Amps. (*i.e.*, Force × Velocity).

A certain power operates for a certain length of time, and in consequence a certain amount of work is done or an amount of energy is produced or consumed.

A 10 H.P. engine works for 10 minutes.
Work done = 330,000 ft.-lbs. per min. for 10 mins.
= 3,300,000 ft.-lbs.

Or, a 40 watt lamp burns for 10 mins.

Energy consumed from mains
= 40 joules per sec. for 600 secs.
= 24,000 joules, which is expended in the form of light and heat.

A power of $I^2R$ or $EI$, or $\frac{E^2}{R}$ watts for t secs. gives $I^2Rt$, or $EIt$, or $\frac{E^2}{R}t$ joules.

Energy cannot be created or destroyed. The total amount of energy in the Universe is constant. It is merely converted from one form into another.

When we speak of energy being "produced" we mean to imply that we have obtained it in one form from another form. And when we say that energy is "wasted" or "lost" we do not imply that it is destroyed, but that it has escaped from us as it was impracticable or inconvenient for us to utilise it.

The source of most of the energy that we "produce" and utilise is coal. Coal is a store-house of energy derived from the heat energy of the sun in ages past.

We liberate this energy from coal in furnaces and utilise a fraction of it to heat water in boilers, *i.e.*, transfer the heat energy to the water and produce steam.

By the medium of steam at high pressure we create motion in engines. We have converted the heat energy (or some of it) into mechanical energy.

An engine drives a dynamo, and electrical energy results. Mechanical energy has been converted into electrical energy.

The latter is utilised to burn electric lamps resulting in light and heat again; to run electric motors (mechanical energy); to radiate electromagnetic waves through the ether, ultimately producing sound (mechanical vibrations in the receiving telephones). And so on.

At every stage we "lose" energy in overcoming friction in various forms. But it is not actually lost; it is converted mostly into heat which is given to the earth or atmosphere and there it serves to assist the multitudinous processes of nature.

# APPENDIX B.

## BRITISH STANDARD LIST OF TERMS AND DEFINITIONS USED IN RADIO COMMUNICATION.

NOTE.—Throughout the List the word WIRELESS may be used in substitution for the word RADIO.

| Term. | Definition. |
|---|---|
| **Absorption** | The reduction in amplitude of an ether wave due to causes other than the geometrical attenuation. |
| **Aerial**<br>ANTENNA. | The system of conductors established at a radio station for the purpose of radiating or absorbing ether waves.<br>This expression does not include the arrangements for making electrical connection to earth or its equivalent, or the tuning arrangements. |
| **Aerial Current** | The current (R.M.S. value unless otherwise stated) in an aerial system measured at an antinode of current. |
| **Aerial Effect** | A non-directional disturbing effect occurring in a directional receiver due to lack of symmetry in the disposition of stray capacity in the receiving apparatus. |
| **Aerial Resistance.** | The total effective resistance offered by an aerial system at a particular wave-length. The figure expressing this resistance, multiplied by the square of the aerial current, is a measure of the total power dissipated by the aerial, the radiated power being included. |
| **Aerial System** | The combination of an aerial with its earth arrangements, and tuning arrangements. |
| **Amplifier** | A device by means of which the input-power is used to control a local source of energy in such a way that, provided the limits of saturation are not reached there is an approximately proportional relation between the magnitudes of the controlling and the controlled powers, without sensible change in wave form. |
| **Amplification** | The process by which, or the extent to which, an amplifier increases power, voltage or current without sensible change in wave form. |
| **Amplification Factor** | Of power, voltage or current. The ratio of the power, voltage, or current available at the output terminals of an amplifying device to the power, voltage, or current at the input terminals under certain specified conditions, such as given output or given input. The amplitude in each case must be such that no saturation or threshold effects of any kind are involved. |
| **Amplification Ratio.** | Of 3-electrode thermionic valve. The numerical ratio of the slope of the anode current/grid voltage characteristic curve to the slope of the anode current/anode voltage characteristic curve of the 3-electrode thermionic valve, the slope in each case being that at the point representing the particular adjustments under consideration. |

| Term. | Definition. |
|---|---|
| **Anode** | The principal electrode for the collection of the electrons forming the emission current of a thermionic valve. |
| **Anode Current** | The current flowing between the anode and the remaining electrodes of a thermionic valve. |
| **Anode Tapping Point.** | The point on the inductance in the main oscillating circuit of a valve generator which is connected to the anode of the valve. |
| **Anode Voltage** | The voltage between the anode and the negative terminal of the filament of a thermionic valve.<br>NOTE.—When the filament is heated by an alternating current, the voltage is measured between the anode and the centre point of the filament. |
| **Antinode** | In a system which has a non-uniform distribution of R.M.S. current or voltage, any point at which the R.M.S. value is at its maximum is called an antinode of current or of voltage respectively. |
| **Arc**<br>*Ab. for Arc Transmitter.* | A device which generates oscillations by means of the electric arc. |
| **Asymmetrical Effect.** | The non-directional effect resulting in a loop or frame aerial from lack of symmetry in its construction. |
| **Asynchronous Spark Gap.** | A rotary spark gap arranged to give a number of sparks in each cycle of an alternating current supply, the sparks not necessarily occurring at points of the same phase in successive cycles. |
| **Atmospherics**<br>ATMOSPHERIC DISTURBANCES. | Stray ether waves due to natural causes. The term is also applied to the false signals produced thereby. |
| **Attenuation** | The total reduction in amplitude of an ether wave at progressively increasing distances from the point of origin. |
| **Geometrical Attenuation** | The reduction in amplitude of an ether wave due to the expansion of the wave front as the distance from its source increases. |
| **Auto-Capacity Coupling.** | The coupling between two oscillatory systems due to a condenser common to both. |
| **Auto-Heterodyne** | A receiving device which generates the local oscillations required for beat reception in addition to performing its other functions, such as amplification or detection. |
| **Auto-Inductive Coupling.** | The coupling between two oscillatory systems due to an inductance common to both. |
| **Beat** | The rise and fall of resultant amplitude due to the combination of oscillations of two different frequencies. |
| **Beat Reception** | Reception by means of the combination of a locally generated alternating current with the alternating current resulting from incoming signals, the two being of different frequencies. |
| **Blue Glow** | A blue light sometimes visible within the bulb of an ionic valve, resulting from ionization. |
| **Buried Aerial** | An aerial buried in the ground. |
| **Buzzer** | A low-power generator of damped oscillations used for tuning radio circuits. |

| Term. | Definition. |
|---|---|
| **Capacity Coupling.** | The coupling between two oscillatory systems due to capacity between points of the circuits normally at different potentials. |
| **Carrier Wave** | The wave corresponding in frequency to the continuous oscillation used in radio communication which is modulated, by speech in the case of Type A3 Waves, or by some form of low frequency oscillation in the case of Type A2 Waves. |
| **Characteristic Curves.** | Of a 3-electrode thermionic valve. The four curves taken under non-oscillating conditions, the co-ordinates of which give simultaneous values of :—<br>(1) The anode current and grid voltage; the anode voltage and the electron emission remaining constant.<br>(2) The anode current and anode voltage; the grid voltage and electron emission remaining constant.<br>(3) The grid current and grid voltage; the anode voltage and electron emission remaining constant.<br>(4) The grid current and anode voltage; the grid voltage and electron emission remaining constant. |
| **Characteristic Surface.** | Of a valve. A surface defined by co-ordinates representing simultaneous values of the anode voltage, the grid voltage, and either the anode current or the grid current. The two surfaces are known respectively as the **Anode Current Surface** and **Grid Current Surface.** |
| **Coherer** - - | An oscillation detector working on a non-self-restoring contact principle. |
| **Control Electrode.** | An electrode so arranged that its potential controls the ionic current between other electrodes. |
| **Counterpoise** -<br>BALANCING CAPACITY. | An insulated group of conductors forming part of an aerial system used instead of, or supplementary to, a direct continuity connection to earth. . |
| **Coupling** - | The association between two oscillatory systems whereby a transference of energy from one system to the other is made possible. |
| **Coupling Factor.**<br>COUPLING COEFFICIENT. | The factor depending upon the constants of any two of a group of coupled circuits which determines, for any given resistance and tuning of the circuits, the rate of transfer of energy between these two circuits. With different forms of coupling the factors are differently expressed. In each case the factor has the same physical significance and appears in equations expressing the electrical conditions in the circuit in the same way. |
| **Damped Oscillation.** | An oscillation the amplitude of which progressively decreases. |
| **Dead-end Effect.** | The result in an oscillatory circuit of the presence of idle turns of an inductance. |

| Term. | Definition. |
|---|---|
| **Dead Space** - | A term applied in connection with the special case of beat reception in which no beats are audible owing to the two frequencies being identical or very near together. |
| **Decay Coefficient.** | Of an oscillation. The logarithmic decrement divided by the period. |
| **Decremeter** - | An apparatus for measuring the equivalent logarithmic decrement. |
| **Detector** - - | An appliance for converting high-frequency oscillating current (or voltage) into a form capable of affecting an instrument such as a telephone receiver or galvanometer. |
| **Detuning** - | The deliberate tuning of a radio circuit to a frequency slightly different from that of the wave to be received or transmitted. |
| **Direct Drive** - | An arrangement whereby the frequency of the oscillations in the aerial is determined by the characteristics of the main oscillating circuit. |
| **Direction Finder.** | A receiver designed to determine the direction of arrival of ether waves. |
| **Directional Receiver.** | A receiver so arranged that the resulting sensitivity is nearly zero in two directions substantially opposite to one another, and is maximum in two directions substantially mid-way between the directions of zero sensitivity. |
| **Directional Transmitter.** | A transmitter so arranged that the resulting transmission is nearly zero in two directions substantially opposite to one another, and reaches its maximum value in two directions substantially midway between the directions of zero transmission. |
| **Displacement Current.** | A variation of electric stress in a dielectric. It is equivalent in its magnetic effect to an electric current. |
| **Double Reception.** | Simultaneous reception on two separate wave-lengths on the same aerial. |
| **Double Transmission.** | Simultaneous transmission on two separate wave-lengths from the same aerial. |
| **Earth Screen** - | A screening metallic system interposed between an aerial and the conducting surface of the ground. |
| **Emergency Apparatus.** | Special radio apparatus installed on board ship for use should the main electric supply become inoperative.<br>The word "Emergency" is used as an adjective to distinguish various pieces of apparatus, *e.g.*, Emergency battery. |
| **Equivalent Logarithmic Decrement.** | Of an oscillation. In cases of oscillation in which the amplitude does not decrease in geometrical progression, the apparent value of the logarithmic decrement, as obtained by the usual methods of measurement, is known as the equivalent logarithmic decrement. |
| **Equivalent Logarithmic Increment.** | Of an oscillation. In cases of oscillation in which the amplitude does not increase in geometrical progression, the apparent value of the logarithmic increment, as obtained by the usual methods of measurement, is known as the equivalent logarithmic increment. |

| Term. | Definition. |
|---|---|
| **Ether** | The all-pervading medium postulated by physicists to explain the observed phenomena of electric and magnetic fields. |
| **Ether Waves** | Moving systems of electric and magnetic forces. A single wave is one complete cycle of change of state in the medium. |
| **Fading** | A marked temporary diminution of strength of received signals due to changes not caused by either the transmitting or the receiving stations. |
| **Feed Current** | The direct current component of the anode current. |
| **Feeder** | The electrical conductor joining the overhead portion of an aerial and the remainder of an aerial system. |
| **Filament** | The hot cathode of a thermionic valve forming the source from which the electrons which make up the emission current are set free. |
| **Flat Tuning** | Tuning is said to be flat when the required result can be secured over a wide range of adjustment. |
| **Forced Oscillation.** | An oscillation in a system which is maintained by an external supply of energy and which has the frequency of the external supply, generally different from the fundamental frequency of the system in question. |
| **Frame Aerial** | An aerial consisting of two or more turns of a conductor, usually wound round a frame. |
| **Fundamental Frequency.** | The frequency of a fundamental oscillation. |
| **Fundamental Oscillation.** | The natural oscillation of the lowest frequency. |
| **Fundamental Wave-Length.** | Of a circuit. The wave-length corresponding to the fundamental oscillation of a circuit. (*See* fundamental oscillation.) |
| **Grid** | The control electrode of a thermionic valve. |
| **Grid Battery** | A battery used to produce any desired initial grid voltage. |
| **Grid Current** | The internal current flowing between the grid and the remaining electrodes of a thermionic valve.<br>The normal positive grid current is a current flowing into the valve at the grid. If the current flows in the opposite direction it is called the **Reverse Grid Current.** |
| **Grid Leak** | A resistance connected to the grid circuit of an ionic valve for the purpose of controlling the grid voltage. |
| **Grid Voltage** | The voltage between the grid and the negative terminal of the filament in a thermionic valve.<br>NOTE.—When the filament is heated by an alternating current, the voltage is measured between the grid and the centre point of the filament. |
| **Ground Aerial** | An aerial laid on or near the surface of the ground. |
| **Hard Valve** | A thermionic valve in which the effects of free gas are negligible. |

| Term. | Definition. |
|---|---|
| **Harmonic** | An oscillation having a frequency which is an integral multiple of the fundamental frequency. A harmonic having double the fundamental frequency is called the Second Harmonic and so on. |
| **Heaviside Layer.** | A layer of ionised air above the surface of the earth. |
| **Heterodyne** LOCAL OSCILLATOR. | A device which generates the local oscillations necessary for beat reception. |
| **Independent Drive.** | An arrangement whereby the frequency of the oscillation in the aerial is determined in an independent circuit. |
| **Inductive Coupling.** | The coupling between two oscillatory systems due to the magnetic reaction between separate inductances in those systems. |
| **Interference** | Confusion of reception due to atmospherics, jamming, or other causes. |
| **Ionic Current** | The current carried through a gas or a vacuum by electrons or ions. |
| **Ionic Valve** | A vessel in which a suitable vacuum is maintained and which has two or more electrodes, one at least of which provides a source of free electrons.<br>In the above, the expression "electrode" means a conductor which performs some definite function in connection with the operation of the valve and which has an independent external electrical connection. |
| **Jamming** | Interference due to signals other than those desired. |
| **Limiting Device.** | Any device for limiting the maximum response of a receiver, whatever the strength of the incoming impulse. |
| **Logarithmic Decrement.** | Of an oscillation. When the amplitude of an oscillation decreases in geometrical progression, the Napierian logarithm of the ratio of the maximum displacement of any oscillation to the maximum displacement in the same direction of the immediately succeeding oscillation is known as the logarithmic decrement. |
| **Logarithmic Increment.** | Of an oscillation. When the amplitude of an oscillation increases in geometrical progression, the Napierian logarithm of the ratio of the maximum displacement of any oscillation to the maximum displacement in the same direction of the immediately preceding oscillation is known as the logarithmic increment. |
| **Loop Aerial** | An aerial consisting of a conductor forming a single convolution. |
| **Magnetic Amplifier.** | An amplifier the operation of which depends upon the magnetic properties of ferro-magnetic materials. |
| **Magnetic Detector.** | A form of detector in which the oscillations cause a sudden change in the position of the flux due to a permanent magnet and a revolving iron band, thereby inducing a voltage in a coil in series with a telephone receiver. |
| **Mast** | A structure intended for supporting an aerial; it is generally not self-supporting but requires rigging to enable it to withstand the stresses imposed upon it. |

| Term. | Definition. |
|---|---|
| **Modulator** | An arrangement for causing the amplitude of the oscillations of a carrier wave to vary in accordance with the desired characteristics. |
| **Multiple Tuned Aerial.** | An aerial having a number of leads to earth connected at intervals, each lead having in series a tuning arrangement. |
| **Musical Spark** | A spark discharge of which the rate and regularity of sparking are such as to produce a musical note in the telephone of a receiving station. |
| **Natural Frequency.** | The frequency of a natural oscillation. |
| **Natural Oscillation** | An oscillation in a system having capacity and inductance of which the frequency is solely dependent on the constants of the system. |
| **Natural Wave-Length.** | Of a circuit. The wave-length corresponding to the natural oscillation of a circuit. |
| **Negative Reaction.** | Of a valve circuit. The effect of coupling between parts of an ionic valve, or system of valves, and associated circuits which tends to prevent a state of electrical oscillation in any part of the circuits. |
| **Night Effect** | Irregularities in the strength and/or the apparent direction of arrival of radio signals observable more particularly during the hours of darkness. |
| **Node** | In a system which has a non-uniform distribution of R.M.S. current or voltage, any point at which the R.M.S. value is zero is called a node of current or of voltage respectively. |
| **Note** | The note produced by any regularly interrupted form of transmission, such as Type A2 (interrupted continuous waves) or Type B (spark telegraphy). The numeric employed denotes the number of audible impulses per second. |
| **Note Magnifier** | An amplifier used for amplifying currents or voltages of audible frequency. |
| **Note Tuning**<br>TONE TUNING. | Tuning the parts of a set of receiving instruments to the note frequency of the transmitter, or to the beat frequency when the beat method of reception is in use. |
| **Plain Aerial Transmitter.** | A form of transmitter in which the spark gap is placed directly in series with the aerial. |
| **Quench** | To extinguish completely the spark in the spark gap at the instant when the energy in the primary circuit first becomes zero. |
| **Quenched Spark Gap.** | A spark gap in which the electrodes are so arranged as to quench the spark (*see* Quench). |
| **Radiation** | The emission of energy in the form of electro-magnetic waves. |
| **Radiation Constant.** | Of a transmitter. The product of the radiation height of an aerial system and the aerial current. It is usually expressed in metre-ampères. |
| **Radiation Factor.** | The radiation constant divided by the wave-length. The power radiated is proportional to the square of this factor |

| Term. | Definition. |
|---|---|
| **Radiation Height.** | Of an aerial system. The height of an ideal aerial system consisting of an elevated capacity connected to a perfectly conducting earth by a feeder having no capacity which, for the same aerial current and the same frequency, would produce the same electric field at any given distance as the aerial system in question. |
| **Radiation Resistance.** | Of an aerial system. That component of the aerial resistance which, when multiplied by the square of the aerial current, measures the power radiated. |
| **Radio Beacon** | A radio transmitter intended to aid navigation by emitting characteristic signals. |
| **Radio Communication.** | The art of transmitting signals by means of radiated ether waves. Communication depending on the propagation of such waves guided by tangible conductors between definite receiving stations or on current passing in the earth between electrodes, is not included. |
| **Radio Station** | An installation capable of transmitting and/or receiving. The transmitting and receiving instruments may be separated by a considerable distance. |
| **Radio Telegraphy.** | Radio communication carried out telegraphically. |
| **Radio Telephony.** | Radio communication carried out telephonically. |
| **Reaction** | Of a valve circuit. The effect of coupling between parts of an ionic valve, or system of valves, and associated circuits which tends to produce a state of electrical oscillation in any part of the circuits. |
| **Reaction Coil** | An inductance forming part of the associated circuits of an ionic valve system and primarily intended to cause reaction or negative reaction. |
| **Reaction Condenser.** | A condenser between any two parts of the external circuits of an ionic valve system primarily intended to cause reaction or negative reaction. |
| **Receiver** | A term covering the whole system of receiving apparatus. (This term is not a synonym for Detector. *See* Detector.) |
| **Relay** | A device by means of which the input power is used to control a local source of energy and in which there is no proportional relation between the magnitudes of the controlling and of the controlled powers. |
| **Resistance Coupling.** | The coupling between two oscillatory systems due to a resistance common to both. |
| **Rotary Spark Gap.**<br>DISC DISCHARGER. | A spark gap consisting of a toothed or studded cylinder or disc revolving at a high speed between two fixed electrodes. |
| **Saturation Current.** | Of a thermionic valve. The more or less clearly defined maximum value which can be reached by the feed current of a valve for a given condition of filament temperature under non-oscillating conditions. |

| Term. | Definition. |
|---|---|
| **Selectivity** | The property of a receiving system whereby it is possible to discriminate between a number of simultaneous signals. |
| **Sharp Tuning** | Tuning is said to be sharp when accurate adjustment is necessary to secure the required result. |
| **Shock Excitation.** | The excitation of natural oscillations in an oscillatory system due to a sudden acquisition of energy from an external source. |
| **Simplex Working.** | Alternate transmission and reception at a station using only one aerial. |
| **Soft Valve** | A thermionic valve the properties of which definitely depend upon the presence of free gas. |
| **Space Charge** | The charge of electricity in the space between the electrodes of an ionic valve, due to the presence of free electrons or ions. |
| **Spacing Wave** | The radiation which takes place during the spaces of the telegraphic code when signals are made with continuous wave Type A1 transmitters by means of a variation of the wave-length or of the amplitude of the wave. |
| **Spark Gap** | A piece of apparatus designed for repeated disruptive discharges between its electrodes. |
| **Spark System** | A system of radio-communication in which the waves emitted are caused by the recurring discharges of a condenser across a spark gap. |
| **Speed of Transmission.** | The rate of signalling employed. It is expressed in words per minute, a word being considered to be the equivalent of 5 Morse letters of average length. |
| **Spreader** | A rod or frame used to keep the individual wires of a multiple wire aerial in their relative positions. |
| **Stray-capacity Effect.** | The effect due to unintended capacity existing between those parts of a set of apparatus which are normally at different potentials, or between them and earth. |
| **Submerged Aerial.** | An aerial submerged in water. |
| **Synchronous Spark Gap.** | A rotary spark gap arranged to give a fixed number of sparks in each cycle of an alternating current supply, the sparks occurring at points of the same phase in successive cycles. |
| **Syntonise** | To adjust two or more circuits to the same frequency. |
| **Thermionic Current.** | The ionic current flowing between the electrodes of a thermionic valve. |
| **Thermionic Relay.** | A valve and associated circuits the operation of which is such that they perform the functions of a relay. |
| **Thermionic Valve.**<br>*Valve.* | An ionic valve in which the source of free electrons is an electrode maintained at a suitable temperature by external means.<br>A valve having two electrodes is sometimes known as a **Diode.**<br>A valve having three electrodes is sometimes known as a **Triode.**<br>A valve having four electrodes is sometimes known as a **Tetrode,** and so on. |

| Term. | Definition. |
|---|---|
| **Ticker**<br>TIKKER. | A rapid make and break device used as a receiver of continuous waves. |
| **Timed Spark Transmitter.** | A transmitter so devised that sparks take place with great rapidity, and are separated from one another by a time interval which is an exact multiple of the period of the radiating aerial system, thus producing an oscillation therein which persists without complete disappearance, although there may be some variation of amplitude of the oscillation between consecutive sparks. |
| **Tone Wheel** | A commutator or interrupter, forming part of a receiving circuit, so arranged as to perform either of the following operations :—<br>(*a*) To produce rectification by running synchronously with the received oscillation.<br>(*b*) To convert the high frequency current into an alternating current of low frequency by running asynchronously with the received oscillation. |
| **Tower** | A structure intended for supporting an aerial; it is self-supporting and does not ordinarily require rigging to enable it to withstand the stresses imposed upon it. |
| **Transmit** | To produce electric impulses in a manner capable of conveying signals from one station to another. |
| **Transmitter** | An instrument, or group of instruments, by which transmission can be effected. |
| **Trigger Relay** | A relay which, when operated, undergoes changes in regard to its electrical equilibrium such that it remains in its new condition until reset. |
| **Tuning** | Adjusting radio instruments for the purpose of transmission or reception on any particular wave-length. |
| **Undamped Oscillation.** | An oscillation, whether forced or natural, the amplitude of which is constant. |
| **Uni-Directional Receiver.** | A receiver so arranged that the resulting sensitivity is nearly zero in one direction and is maximum in substantially the opposite direction. |
| **Uni-Directional Transmitter.** | A transmitter so arranged that the resulting transmission is nearly zero in one direction, and reaches its maximum value in substantially the opposite direction. |
| **Unloaded Wave-length.** | Of an aerial. The fundamental wave-length of an aerial system when no tuning inductances or condensers are used. This has been frequently referred to as the "natural wave-length" of the aerial, but the use of this term is here deprecated and should be reserved for the meaning given to "Natural Wave-length." |
| **Variometer** | A form of variable inductance in which the variation is made without alteration to the amount of conductor in the circuit. |
| **Wandering** | The alteration of apparent direction of received signals due to changes not caused by either the transmitting or the receiving stations. |

| Term. | Definition. |
|---|---|
| **Wave-Length** - | The distance between corresponding phases of consecutive waves in a wave-train measured in the direction of propagation at any instant. |
| **Wavemeter** | An instrument for measuring radio frequencies. It is usually calibrated in wave-lengths. |
| **Wave Train** - | A group of successive waves related to one another, cyclical or nearly cyclical in form. |
| **Wave Velocity** | The rate of advance of any phase of a wave. |
| **Continuous Waves.**<br>TYPE A WAVES. | A sequence of waves produced without interruption or variation. Waves which, after reaching the steady state, are periodic, *i.e.*, the successive oscillations are identical. |
| **Type A1 Waves.**<br>CONTINUOUS WAVES UNMODULATED, KEY CONTROLLED.<br>*C.W.* | Continuous waves in which a variation of amplitude and/or of frequency is made by the operation of keying for the purposes of telegraphic transmission.* |
| **Type A2 Waves.**<br>CONTINUOUS WAVES, MODULATED AT AUDIBLE FREQUENCY, KEY CONTROLLED, INTERRUPTED CONTINUOUS WAVES. | Continuous waves in which a variation of amplitude and/or of frequency is made in a periodic manner at an audible frequency and key controlled for the purposes of telegraphic communication.* |
| *I.C.W.* - - | The term **Tonic Train** is applied to Type A2 Waves, when the modulation is approximately sinusoidal. |
| **Type A3 Waves.**<br>CONTINUOUS WAVES, MODULATED BY SPEECH. | Continuous waves in which a variation of amplitude and/or of frequency is made in accord with the characteristic vibrations of speech. |
| **Damped Waves.**<br>TYPE B WAVES. | Waves forming successive wave trains in each of which the amplitude, after reaching its maximum, progressively decreases.* |

*NOTE.—Telegraphy carried out by means of Type A1 Waves implies that each unit of the telegraphic code employed is conveyed by one unbroken series of waves. Telegraphy carried out by means of Type A2 Waves or Type B Waves implies that each unit of the telegraphic code is conveyed by a series of clearly separated groups of waves.

# APPENDIX C.

## MAGNETIC AND ELECTRICAL UNITS.—WITH MORE PARTICULAR REFERENCE TO ABSOLUTE UNITS.

The following brief notes have been drawn up, with a view to a better understanding of units, and their derived formulæ, met with in W/T.

### Force.

*The Absolute Unit is the Dyne,* and is that force which will produce unit acceleration of 1 cm. per sec. per sec. in unit mass (1 gramme).

*The Practical Unit is the Gramme.*

1 Gramme = 981 (or " g ") dynes, where " g " is the acceleration due to gravity (981 cms. per sec. per sec.).

The dyne is a very small force, used in scientific measurements, being equivalent to about $\frac{1}{445000}$ lb.

### Work or Energy.

*The Absolute Unit is the Erg,* and is that amount of work done by a force of 1 dyne acting for a distance of 1 cm.

*The Practical Unit is the Joule.*

1 joule = $10^7$ ergs.

### Power.

Is the *rate* of doing work (of expending or consuming energy).

*Absolute Unit*—1 erg per sec.

*Practical Unit*—$10^7$ ergs per sec. = 1 joule per sec. = 1 watt.

### Unit Magnetic Pole.

(*a*) A pole of 1 unit acts on another pole of 1 unit at a distance of 1 cm., with a force of 1 dyne.

(*b*) A pole of 1 unit acts on another pole of 1 unit at a distance of d cms. with a force of $\frac{1}{d^2}$ dynes.

(*c*) A pole of M units acts on another pole of n units, at a distance of d cms., with a force of $\frac{Mn}{d^2}$ dynes.

### Unit Field.

Unit Field is said to exist where a unit pole is acted on with a force of 1 dyne.

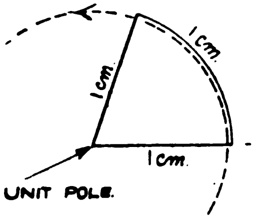
From the foregoing it can be seen that unit field exists at any point 1 cm. from a unit pole. That is to say, a unit pole is surrounded with a shell of unit field, the shell being the surface of a sphere 1 cm. radius.

The surface of a sphere is $4\pi r^2$ square cms. or $4\pi$ square cms., as the radius is taken as unity in the above case.

Unit field is also defined as 1 line of force per square cm. So $4\pi$ lines of force emanate from 1 unit pole.

**Current.**

The absolute C.G.S., or *electromagnetic* unit of current is such that if flowing in an arc of a circle 1 cm. long, the radius of circle being 1 cm. it acts on a unit pole at the centre with a force of 1 dyne.



Action and reaction are equal and opposite, so that this arc is acted on with a force of 1 dyne.

If it were " e " cms. long instead of 1 cm., it would be acted on with a force of " e " dynes.

*The Practical Unit is the Ampère.*

1 ampere = $\frac{1}{10}$ absolute or e.m. unit = $3 \times 10^9$ absolute or e.s. units.

**Quantity.**

*The Absolute Electromagnetic unit quantity* of electricity is that conveyed by absolute unit current in one second.

*The Practical Unit is the Coulomb*, and is the quantity conveyed by 1 ampere in 1 second.

1 coulomb = $\frac{1}{10}$ absolute e.m. unit.

(N.B.—Practical units are generally much greater in magnitude than the corresponding absolute units. The units of current and quantity are exceptions in this respect.)

So far we have been dealing in *practical units* and in *absolute electromagnetic* units. Another system of units, also based on the centimetre, gramme and second, called *electrostatic* units, is in use. The relation between the absolute units of quantity in the two systems is the velocity of light ($v$) in cm. per second. This velocity is $3 \times 10^{10}$ cm. per sec., and the *electromagnetic* unit of quantity = $3 \times 10^{10}$ *electrostatic* units.

Thus 1 coulomb = $\frac{1}{10}v = 3 \times 10^9$ abs. electrostatic (e.s.) units.

**E.M.F.**

Two points on a conductor are said to have *absolute electromagnetic unit E.M.F. or P.D.* between them when 1 erg of work is done by the electric forces in urging absolute e.m. unit quantity of electricity from one point to the other.

*The Practical Unit is the Volt.*

1 volt = $10^8$ absolute e.m. units.

Also 1 volt = $\frac{10^8}{3 \times 10^{10}} = \frac{1}{300}$ absolute electrostatic unit.

**Resistance.**

The units of resistance are derived from those of current and E.M.F. A conductor has *absolute electromagnetic unit resistance* if absolute e.m. unit P.D. applied to its ends causes absolute e.m. unit current to flow.

*The Practical Unit is the Ohm.* Similarly, the resistance of a conductor is 1 ohm when 1 ampere flows with applied P.D. of 1 volt.

$$\text{From Ohm's Law, 1 ohm} = \frac{\text{1 volt.}}{\text{1 amp.}}$$

$$\text{1 ohm} = \frac{10^8 \text{ e.m. units}}{10^{-1} \text{ e.m. units}} = 10^9 \text{ e.m. units.}$$

*See also* Chapter II., p. 19, for Legal Standard Ohm.

### Magnetic Flux.

Is measured in " lines " (*i.e.*, lines of force). (The term " Maxwell " is also used for the unit of flux.)

### Flux Density.

Is measured in " *lines per sq. cm.*" (The unit of flux density is termed the " Gauss.")

### Reluctance.

The unit of Reluctance $= S = \frac{l}{a\mu}$ c.g.s. units or " Oersteds."

### Permeability.

It will be remembered that the " Co-efficient of Permeability " is a *ratio*, *i.e.*, no unit, just a plain number (*see* para. 89).

### Magneto-Motive Force (M.M.F.).

The common measure of M.M.F. is simply so many *units*, but the term " Gilbert " is also used. Thus we have for the magnetic circuit :—

$$\text{Maxwells} = \frac{\text{Gilberts}}{\text{Oersteds}}.$$

(The names Maxwell, Gilbert, Oersted, Gauss, are not frequently used and need not be remembered.)

Thus :—

$$\text{Flux (" lines ")} = \frac{\text{M.M.F.}}{\text{Reluctance (S)}} = \frac{4\pi \text{ IN (" units ")}}{\frac{l}{a\mu} \text{ (" units ")}}$$

### Self-Inductance.

The self-inductance of a circuit in *absolute or electromagnetic units* is the number of *linkages* when absolute unit current is flowing.

$$\begin{aligned}\text{Linkages} &= \text{Flux} \times \text{Turns.}\\ &= \frac{4\pi N}{S} \times N = \frac{4\pi N^2}{S}.\end{aligned}$$

*i.e.*, $\frac{4\pi N^2}{S}$ absolute e.m. or C.G.S. units or " centimetres."

N.B.—From a study of the " Theory of Units " it is found that the dimensions of inductance (and of capacity and resistance) are the same as those of length. Hence the term " centimetres." This matter cannot be discussed more fully here.

*The Practical Unit is the Henry.* A circuit has an inductance of 1 Henry when an E.M.F. of 1 volt is induced if the current is changing at the rate of 1 ampere per sec. (*see* para. 64).

1 Henry $= 10^9$ abs. e.m. units, or cms.

$$\text{Also 1 Henry} = \frac{10^9}{v^2} \text{ electrostatic units,}$$

where v = velocity of light = $3 \times 10^{10}$ cm. per sec.

$$= \frac{1}{9 \times 10^{11}} \text{ e.s. units,}$$

but this is not usually required in our work.

## Mutual Inductance.

The units of Mutual Inductance are the same as those of Self-Inductance (*see* para. 120).

## Capacity.

A condenser has a capacity of one *absolute electrostatic unit or centimetre* if absolute e.s. unit quantity of electricity produces a P.D. of one absolute e.s. unit between its plates.

*The Practical Unit is the Farad.*

1 coulomb produces a P.D. of 1 volt when the capacity is one farad (*see* para. 128).

1 farad $= \frac{v^2}{10^9} = \frac{9 \times 10^{20}}{10^9} = 9 \times 10^{11}$ absolute e.s. units or centimetres.

1 farad $= 9 \times 10^8$ Jars, thus 1 jar = 1,000 abs. e.s. units or cms.

Note that in the case of Capacity we deal customarily with absolute *electrostatic* units.

Thus we have :—Q = C V

1 Coulomb = 1 farad × 1 volt.

$$= 9 \times 10^{11} \times \frac{1}{300} = 3 \times 10^9 \text{ e.s. units.}$$

the equation is therefore true in the case of both practical and absolute units.

# APPENDIX D.

## TABLE I.

The following conversion table is based on the formulae

$$\text{kc.} = \frac{3 \times 10^5}{\lambda} \text{ and LC} = \left(\frac{\lambda}{20\pi}\right)^2 \text{ where}$$

kc. = frequency in kilocycles.
$\lambda$ = wave-length in metres.
LC = oscillation constant, in microhenries and jars.

To obtain the LC value in microhenries and microfarads, the values given in the LC column should be divided by 30.

It should be noted that wave-length and frequency are reciprocal; *i.e.*, 50 metres correspond to 6,000 kc., and 50 kc. to 6,000 metres.

| λ in Metres | Frequency in Kilocycles. | L.C. Value (mic.–jars). | λ in Metres | Frequency in Kilocycles. | L.C. Value (mic.–jars). |
|---|---|---|---|---|---|
| 1 | 300,000 | 0·0002533 | 37 | 8,108 | 0·3468 |
| 2 | 150,000 | 0·001013 | 38 | 7,895 | 0·3658 |
| 3 | 100,000 | 0·002280 | 39 | 7,692 | 0·3853 |
| 4 | 75,000 | 0·004053 | 40 | 7,500 | 0·4053 |
| 5 | 60,000 | 0·006333 | 41 | 7,317 | 0·4258 |
| 6 | 50,000 | 0·009119 | 42 | 7,143 | 0·4469 |
| 7 | 42,855 | 0·01241 | 43 | 6,977 | 0·4684 |
| 8 | 37,500 | 0·01621 | 44 | 6,818 | 0·4904 |
| 9 | 33,333 | 0·02052 | 45 | 6,667 | 0·5129 |
| 10 | 30,000 | 0·02533 | 46 | 6,522 | 0·5360 |
| 11 | 27,273 | 0·03065 | 47 | 6,383 | 0·5595 |
| 12 | 25,000 | 0·03647 | 48 | 6,250 | 0·5836 |
| 13 | 23,077 | 0·04281 | 49 | 6,122 | 0·6082 |
| 14 | 21,429 | 0·04965 | 50 | 6,000 | 0·6338 |
| 15 | 20,000 | 0·05699 | 55 | 5,454 | 0·7662 |
| 16 | 18,750 | 0·06485 | 60 | 5,000 | 0·9119 |
| 17 | 17,647 | 0·07320 | 65 | 4,615 | 1·070 |
| 18 | 16,666 | 0·08207 | 70 | 4,286 | 1·241 |
| 19 | 15,789 | 0·09144 | 75 | 4,000 | 1·425 |
| 20 | 15,000 | 0·1013 | 80 | 3,750 | 1·625 |
| 21 | 14,285 | 0·1117 | 85 | 3,529 | 1·830 |
| 22 | 13,636 | 0·1226 | 90 | 3,333 | 2·052 |
| 23 | 13,043 | 0·1340 | 95 | 3,158 | 2·286 |
| 24 | 12,500 | 0·1459 | 100 | 3,000 | 2·533 |
| 25 | 12,000 | 0·1583 | 105 | 2,857 | 2·793 |
| 26 | 11,538 | 0·1712 | 110 | 2,727 | 3·065 |
| 27 | 11,111 | 0·1847 | 115 | 2,609 | 3·350 |
| 28 | 10,714 | 0·1986 | 120 | 2,500 | 3·648 |
| 29 | 10,345 | 0·2130 | 130 | 2,308 | 4·281 |
| 30 | 10,000 | 0·2280 | 140 | 2,143 | 4·965 |
| 31 | 9,677 | 0·2434 | 150 | 2,000 | 5·699 |
| 32 | 9,375 | 0·2594 | 160 | 1,875 | 6·485 |
| 33 | 9,091 | 0·2758 | 170 | 1,765 | 7·320 |
| 34 | 8,823 | 0·2928 | 180 | 1,667 | 8·207 |
| 35 | 8,571 | 0·3103 | 190 | 1,579 | 9·144 |
| 36 | 8,333 | 0·3283 | 200 | 1,500 | 10·13 |

| λ in Metres | Frequency in Kilocycles. | L.C. Value (mic.–jars). | λ in Metres | Frequency in Kilocycles. | L.C. Value (mic.–jars). |
|---|---|---|---|---|---|
| 210 | 1,429 | 11·17 | 1,550 | 193·5 | 608·6 |
| 220 | 1,364 | 12·26 | 1,600 | 187·5 | 648·5 |
| 230 | 1,304 | 13·40 | 1,650 | 181·8 | 689·6 |
| 240 | 1,250 | 14·59 | 1,700 | 176·5 | 732·0 |
| 250 | 1,200 | 15·83 | 1,740 | 172·4 | 766·9 |
| 260 | 1,154 | 17·12 | 1,750 | 171·4 | 775·7 |
| 270 | 1,111 | 18·47 | 1,800 | 166·7 | 820·7 |
| 280 | 1,071 | 19·86 | 1,850 | 162·2 | 866·9 |
| 290 | 1,034 | 21·30 | 1,900 | 157·9 | 914·4 |
| 300 | 1,000 | 22.80 | 1,950 | 153·8 | 963·2 |
| 310 | 967·7 | 24·34 | 1,980 | 151·5 | 993·0 |
| 320 | 937·5 | 25·94 | 2,000 | 150·0 | 1,013 |
| 330 | 909·1 | 27·58 | 2,100 | 142·9 | 1,117 |
| 340 | 882·3 | 29·28 | 2,200 | 136·4 | 1,226 |
| 350 | 857·1 | 31·03 | 2,300 | 130·4 | 1,340 |
| 360 | 833·3 | 32·83 | 2,400 | 125·0 | 1,459 |
| 370 | 810·8 | 34·68 | 2,500 | 120·0 | 1,583 |
| 380 | 789·5 | 36·58 | 2,600 | 115·4 | 1,712 |
| 390 | 769·2 | 38·53 | 2,700 | 111·1 | 1,847 |
| 400 | 750·0 | 40·53 | 2,800 | 107·1 | 1,986 |
| 410 | 731·7 | 42·58 | 2,900 | 103·4 | 2,130 |
| 420 | 714·3 | 44·68 | 3,000 | 100·0 | 2,280 |
| 430 | 697·7 | 46·84 | 3,100 | 96·77 | 2,434 |
| 440 | 681·8 | 49·04 | 3,200 | 93·75 | 2,594 |
| 450 | 666·7 | 51·29 | 3,300 | 90·91 | 2,758 |
| 460 | 652·2 | 53·60 | 3,400 | 88·24 | 2,928 |
| 470 | 638·3 | 55·95 | 3,500 | 85·71 | 3,103 |
| 480 | 625·0 | 58·36 | 3,750 | 80·00 | 3,562 |
| 490 | 612·2 | 60·82 | 3,800 | 78·95 | 3,658 |
| 500 | 600·0 | 63·33 | 3,900 | 76·92 | 3,853 |
| 510 | 588·2 | 65·88 | 4,000 | 75·00 | 4,053 |
| 520 | 576·9 | 68·49 | 4,200 | 71·34 | 4,468 |
| 530 | 566·0 | 71·15 | 4,250 | 70·59 | 4,575 |
| 540 | 555·6 | 73·86 | 4,500 | 66·67 | 5,129 |
| 550 | 545·4 | 76·62 | 4,700 | 63·83 | 5,595 |
| 560 | 535·7 | 79·44 | 4,750 | 63·16 | 5,715 |
| 570 | 526·3 | 82·30 | 5,000 | 60·00 | 6,333 |
| 580 | 517·1 | 85·21 | 5,500 | 54·54 | 7,662 |
| 590 | 508·5 | 88·17 | 6,000 | 50·00 | 9,119 |
| 600 | 500·0 | 91·19 | 6,500 | 46·15 | 10,702 |
| 650 | 461·5 | 107·0 | 7,000 | 42·86 | 12,412 |
| 700 | 428·6 | 124·1 | 7,500 | 40·00 | 14,248 |
| 750 | 400·0 | 142·5 | 8,000 | 37·50 | 16,211 |
| 800 | 375·0 | 162·1 | 8,500 | 35·29 | 18,301 |
| 850 | 352·9 | 183·0 | 8,750 | 34·29 | 19,393 |
| 900 | 333·3 | 205·2 | 9,000 | 33·33 | 20,517 |
| 950 | 315·8 | 228·6 | 9,500 | 31·58 | 22,861 |
| 1,000 | 300·0 | 253·3 | 10,000 | 30·00 | 25,330 |
| 1,500 | 285·7 | 279·3 | 11,000 | 27·27 | 30,650 |
| 1,100 | 272·7 | 306·5 | 12,000 | 25·00 | 36,476 |
| 1,150 | 260·9 | 335·0 | 12,400 | 24·19 | 38,948 |
| 1,200 | 250·0 | 364·8 | 13,000 | 23·08 | 42,808 |
| 1,240 | 241·9 | 389·5 | 14,000 | 21·43 | 49,647 |
| 1,250 | 240·0 | 395·8 | 15,000 | 20·00 | 56,993 |
| 1,290 | 232·6 | 421·5 | 16,000 | 18·75 | 64,846 |
| 1,300 | 230·8 | 428·1 | 17,000 | 17·65 | 73,204 |
| 1,350 | 222·2 | 461·6 | 18,000 | 16·67 | 82,070 |
| 1,400 | 214·3 | 496·5 | 19,000 | 15·79 | 91,442 |
| 1,410 | 212·8 | 503·6 | 20,000 | 15·00 | 101,321 |
| 1,450 | 206·9 | 532·6 | 25,000 | 12·00 | 158,314 |
| 1,480 | 202·7 | 554·8 | 30,000 | 10·00 | 227,973 |
| 1,500 | 200·0 | 569·9 | | | |

## TABLE II.

### Summary of useful formulæ.

(Unless otherwise stated, L and C denote mics and jars respectively.)

Para. 44. The resistance of a conductor to continuous currents :—

$$R = \rho \frac{l}{a}$$

R = resistance in ohms.
l = length of conductor in cms.
a = cross-section conductor in sq. cms.
$\rho$ = specific resistance in ohms per cm. cube.

Para. 115. Inductance of a coil :—

$$L = rN^2F$$

r = mean radius of coil in inches.
N = number of turns of coil.
F = "form factor" of coil, found from curve in Fig. 40.

Para. 134. Capacity of a parallel-plate condenser :—

$$C = \frac{AKn}{5000d}$$

A = area of one plate in sq. ins.
K = S.I.C. of dielectric.
n = number of dielectrics under strain.
d = thickness of dielectric in inches.

Para. 221. Value of current through an inductance :—

$$I = \frac{V}{\omega L}$$

$\omega = 2\pi \times f$ (frequency of applied voltage V).
L = inductance in henries.

Para. 224. Value of current through inductance and resistance in series :—

$$I = \frac{V}{\sqrt{R^2 + (\omega L)^2}}$$

L in henries.

Para. 230. Value of current through a condenser :—

$$I = \omega CV$$

C = capacity of condenser in farads.

Para. 232. Value of current through condenser, inductance and resistance in series :—

$$I = \frac{V}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

$\left.\begin{array}{l}\text{L in henries,}\\ \text{C in farads.}\end{array}\right\}$

Paras. 233, 303. Frequency of an oscillatory circuit.

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \left\{\begin{array}{l}\text{f in cycles.}\\ \text{L in henries.}\\ \text{C in farads.}\end{array}\right.$$

$$f = \frac{3 \times 10^7}{2\pi\sqrt{LC}} = \frac{4{\cdot}8 \times 10^6}{\sqrt{LC}}* \qquad \left\{\begin{array}{l}\text{f in cycles.}\\ \text{L in mics.}\\ \text{C in jars.}\end{array}\right.$$

$$f = \frac{3 \times 10^4}{2\pi\sqrt{LC}} = \frac{4{\cdot}8 \times 10^3}{\sqrt{LC}}* \qquad \left\{\begin{array}{l}\text{f in kilocycles.}\\ \text{L in mics.}\\ \text{C in jars.}\end{array}\right.$$

Para. 241. Voltage across the condenser or inductance in a resonant circuit :—

$$V = 30\,I\sqrt{\frac{L}{C}}.$$

Para. 250. Circulating current in a closed resonant circuit with V volts applied :—

$$I = \frac{V}{30}\sqrt{\frac{C}{L}}.$$

---

* Very approximately.

Para. 254. Supply current required to maintain an oscillation in a closed resonant circuit containing a resistance of R ohms (where R is small) :—

$$1 = \frac{V \times R \times C}{900 \times L},$$

Para. 260. Power expenditure in any alternating current circuit :—

$\text{Watts} = I^2 R$ $\qquad I$ = R.M.S. current.

$\qquad = I \times V \cos \phi$ $\qquad V$ = R.M.S. voltage.

$\qquad \phi$ = angle of lag or lead.

Para. 301. Period of an oscillatory circuit :—

$$\tau = \frac{2\pi \sqrt{LC}}{3 \times 10^7} \text{ seconds.}$$

Para. 302. Wave-length of an oscillatory circuit :—

$$\lambda = 20\pi \sqrt{LC} = 62 \cdot 8 \sqrt{LC} \text{ approx.}$$

$$\lambda = 1885 \sqrt{LC} \begin{cases} \text{L in mics,} \\ \text{C in microfarads.} \end{cases}$$

Para. 320. Coupling between two resonant circuits containing inductances $L_1$ and $L_2$, and having mutual inductance M :—

$$k = \frac{M}{\sqrt{L_1 L_2}}.$$

Percentage coupling = k × 100

The two resultant wave-lengths are—

$$\lambda_1 = \lambda \sqrt{1 + k} \text{ and } \lambda_2 = \lambda \sqrt{1 - k}$$

where $\lambda$ is the wave to which the circuits are separately tuned.

Para. 331. Decrement due to resistance :—

$$\delta = \frac{R'}{9 \cdot 6} \sqrt{\frac{C}{L}}$$ $R'$ = high frequency resistance.

Para. 332. Decrement due to insulation leakage :—

$$\delta = \frac{94}{R} \sqrt{\frac{L}{C}}$$ R = insulation resistance.

Para. 333. Radiation resistance :—

$$= 1600 \frac{h^2}{\lambda^2} \begin{cases} h = \text{radiation height of aerial in metres.} \\ \lambda = \text{wave-length in metres.} \end{cases}$$

Para. 352. To determine resonant frequency of a charging circuit in a spark installation :—

$$f = \frac{4 \cdot 8 \times 10^6}{T \sqrt{LC}} \text{ where} \begin{cases} T = \text{transformation ratio of transformer.} \\ L = \text{inductance in low tension circuit.} \\ C = \text{capacity of transmitting condenser.} \end{cases}$$

Para. 362. Power taken to charge a condenser of C jars up to a discharging voltage of V volts at a spark train frequency N :—

$$\text{kW.} = \frac{1}{2} \times \frac{CV^2N}{9 \times 10^{11}}.$$

**Distance between two points on earth's surface.**

Let $\theta$ and $a$ be lat. and long. of station A.

Let $\theta'$ and $a'$ be lat. and long. of station B.

Let $\phi$ be the angle subtended by the arc AB at the centre of the earth.

$$\cos \phi = \sin \theta \sin \theta' + \cos \theta \cos a \cos \theta' \cos a' + \cos \theta \sin a \cos \theta' \sin a'.$$

Then distance A to B—

= d = $60\phi$ miles (where $\phi$ is measured in degrees and decimals of a degree).

## TABLE III.

### Specific Inductive Capacities.

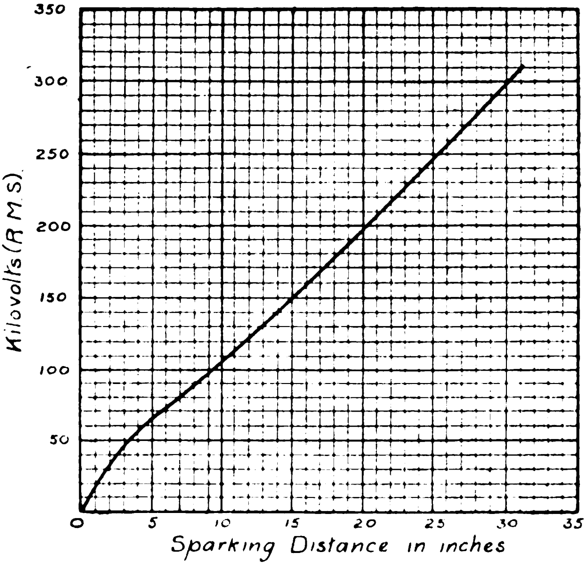
| | | | |
|---|---|---|---|
| Glass, flint | 7–10 | Vulcanite | 2·5 |
| Glass, plate | 5–7 | Porcelain | 4·4–6·8 |
| Ebonite | 2·7–2·9 | Distilled water | 81 |
| Mica | 5·7–7 | Paraffin | 2·0–2·3 |
| Indiarubber | 2·12–2·34 | Service insulating oil | 2·217 |
| Shellac | 3–3·7 | Petroleum and turpentine | 2·2–2·3 |

## TABLE IV.

### Dielectric Strengths.

| Material. | Volts per mm. | Material. | Volts per mm. |
|---|---|---|---|
| Celluloid | 14,000 | Paraffin | 11,500 |
| Ebonite | 30,000 | Porcelain | 9,000–16,000 |
| Empire cloth | 10,000 | Presspahn | 4,000–10,000 |
| Fuller board | 16,000 | Resin | 11,000 |
| Glass, ordinary | 8,000 | Wax | 11,500 |
| Micanite plate | 40,000 | | |

Curve of Sparking Voltages between sharp points in Air.



*Note* 1.—The dielectric strength per unit length falls as the thickness increases. 9,000 v/mm. is that for porcelain 15 mm. thick and 16,000 for 0·5 mm. thickness.

*Note* 2.—The effect of inserting stronger insulation of higher S.I.C. may result in a breakdown of the combination, *e.g.*, if the insulation of a 2 cm. gap between two plates is increased by the insertion of a 0·2 cm. sheet of insulation of S.I.C. 4, and much higher dielectric strength, say, 10kV/mm., and the applied voltage is 60 kV., the combination would break down while the air alone would stand.

## TABLE V.

### Conversion Table.

| | To reduce— | Multiply by |
|---|---|---|
| Length | Kilometres to miles | 0·62 |
| | Kilometres to nautical miles | 0·540 |
| | Metres to yards | 1·1 (1·0936) |
| | Metres to feet | 3·28 |
| | Centimetres to inches | 0·394 |
| | Millimetres to mils | 40 (39·4) |
| | Miles to kilometres | 1·61 |
| | Nautical miles (6,080 feet) to metres | 1,852 |
| | Yards to metres | 0·914 |
| | Feet to metres | 0·305 |
| | Inches to centimetres | 2·54 |
| | Miles to millimetres | 0·0254 |
| Area | Square metres to square yards | 1·2 |
| | Square metres to square feet | 11 (10·76) |
| | Square centimetres to square inches | 0·155 |
| | Square millimetres to square inches | 0·00155 |
| | Square yards to square metres | 0·84 |
| | Square feet to square metres | 0·093 |
| | Square inches to square centimetres | 6·45 |
| | Square inches to square millimetres | 645 |
| Volume | Cubic metres to cubic yards | 1·31 |
| | Cubic metres to cubic feet | 3·53 |
| | Cubic cms. to cubic inches | 0·061 |
| | Cubic yards to cubic metres | 0·76 |
| | Cubic feet to cubic metres | 0·0283 |
| | Cubic inches to cubic cms. | 16·4 |
| Capacity | Litres to cubic feet | 0·35 |
| | Litres to gallons | 0·22 |
| | Cubic metres to gallons | 220 |
| | Gallons to cubic feet | 0·16 |
| | Gallons to cubic inches | 277 |
| | Gallons to cubic centimetres | 45·36 |
| | Gallons to litres | 4·54 |
| | Cubic feet to litres | 28·3 |
| | Cubic inches to cubic cm. | 16·4 |
| Mass | Kilograms to pounds | 2·2 |
| | Kilograms to ounces | 35 (35·3) |
| | Grams to ounces | 0·035 |
| | Grams to grains | 15·4 |
| | Milligrams to grains | 0·0154 |
| | Cwt. to kilograms | 50 (50·8) |
| | Pounds to kilograms | 0·45 |
| | Pounds to grams | 454 (453·6) |
| | Ounces to grams | 28·35 |
| | Grains to grams | 0·065 |
| | Grains to milligrams | 65 (64·8) |
| | Pounds avoir. to grains | 7,000 |
| Water | Litres of water to lbs. | 2·2 |
| | Pounds of water to litres | 0·454 |
| | Gallons of water to lbs. | 10 |
| | Pounds of water to gallons | 0·1 |
| | Cubic feet of water to lbs. | 62·3 (62·27) |
| | Cubic feet of salt water to lbs. | 64·3 |
| | Pounds of water to cubic feet | 0·016 |
| | Cubic feet of water to ounces | 998 |
| | Cubic inches of water to grains | 253 |
| | Cubic inches of water to ounces | 0·58 |

| | To reduce— | Multiply by |
|---|---|---|
| Velocity | Feet per minute to miles per hour | 0·0113 |
| | Feet per minute to centimetres per second | 0·508 |
| | Miles per hour to feet per minute | 88 |
| | Kilometres per hour to centimetres per second | 27·8 |
| | Metres per second to feet per minute | 197 |
| | Miles per hour to centimetres per second | 44·7 |
| | Knots to cm. per second | 51·5 |
| Work and Energy. | Joules to ergs | $10^7$ |
| | Joules to foot-lb. | 0·737 |
| | Foot-lb. to joules | 1·356 |
| | Calories (gm.) to joules | 4·180 |
| | Calories to foot-lb. | 3·08 |
| Power | Kilowatts to joules per second | 1,000 |
| | Kilowatts to foot-lb. per second | 737 |
| | Kilowatts to horse power | 1·34 |
| | H.P. to watts | 746 |
| | Foot-lb. per second to watts | 0·042 |

# TABLE VI.

## MATHEMATICAL TABLES.

### LOGARITHMS.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0000 | 0043 | 0086 | 0128 | 0170 | | | | | | 4 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 38 |
| | | | | | | 0212 | 0253 | 0294 | 0334 | 0374 | 4 | 8 | 12 | 16 | 20 | 24 | 28 | 32 | 37 |
| 11 | 0414 | 0453 | 0492 | 0531 | 0569 | | | | | | 4 | 8 | 12 | 15 | 19 | 23 | 27 | 31 | 35 |
| | | | | | | 0607 | 0645 | 0682 | 0719 | 0755 | 4 | 7 | 11 | 15 | 19 | 22 | 26 | 30 | 33 |
| 12 | 0792 | 0828 | 0864 | 0899 | 0934 | 0969 | | | | | 3 | 7 | 11 | 14 | 18 | 21 | 25 | 28 | 32 |
| | | | | | | | 1004 | 1038 | 1072 | 1106 | 3 | 7 | 10 | 14 | 17 | 20 | 24 | 27 | 31 |
| 13 | 1139 | 1173 | 1206 | 1239 | 1271 | | | | | | 3 | 7 | 10 | 13 | 16 | 20 | 23 | 26 | 30 |
| | | | | | | 1303 | 1335 | 1367 | 1399 | 1430 | 3 | 7 | 10 | 12 | 16 | 19 | 22 | 25 | 29 |
| 14 | 1461 | 1492 | 1523 | 1553 | | | | | | | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 28 |
| | | | | | 1584 | 1614 | 1644 | 1673 | 1703 | 1732 | 3 | 6 | 9 | 12 | 15 | 17 | 20 | 23 | 26 |
| 15 | 1761 | 1790 | 1818 | 1847 | 1875 | 1903 | | | | | 3 | 6 | 9 | 11 | 14 | 17 | 20 | 23 | 26 |
| | | | | | | | 1931 | 1959 | 1987 | 2014 | 3 | 5 | 8 | 11 | 14 | 16 | 19 | 22 | 25 |
| 16 | 2041 | 2068 | 2095 | 2122 | 2148 | | | | | | 3 | 5 | 8 | 11 | 14 | 16 | 19 | 22 | 24 |
| | | | | | | 2175 | 2201 | 2227 | 2253 | 2279 | 3 | 5 | 8 | 10 | 13 | 15 | 18 | 21 | 23 |
| 17 | 2304 | 2330 | 2355 | 2380 | 2405 | 2430 | | | | | 3 | 5 | 8 | 10 | 13 | 15 | 18 | 20 | 23 |
| | | | | | | | 2455 | 2480 | 2504 | 2529 | 2 | 5 | 7 | 10 | 12 | 15 | 17 | 19 | 22 |
| 18 | 2553 | 2577 | 2601 | 2625 | 2648 | | | | | | 2 | 5 | 7 | 9 | 12 | 14 | 16 | 19 | 21 |
| | | | | | | 2672 | 2695 | 2718 | 2742 | 2765 | 2 | 5 | 7 | 9 | 11 | 14 | 16 | 18 | 21 |
| 19 | 2788 | 2810 | 2833 | 2856 | 2878 | | | | | | 2 | 4 | 7 | 9 | 11 | 13 | 16 | 18 | 20 |
| | | | | | | 2900 | 2923 | 2945 | 2967 | 2989 | 2 | 4 | 6 | 8 | 11 | 13 | 15 | 17 | 19 |
| 20 | 3010 | 3032 | 3054 | 3075 | 3096 | 3118 | 3139 | 3160 | 3181 | 3201 | 2 | 4 | 6 | 8 | 11 | 13 | 15 | 17 | 19 |
| 21 | 3222 | 3243 | 3263 | 3284 | 3304 | 3324 | 3345 | 3365 | 3385 | 3404 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |
| 22 | 3424 | 3444 | 3464 | 3483 | 3502 | 3522 | 3541 | 3560 | 3579 | 3598 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 15 | 17 |
| 23 | 3617 | 3636 | 3655 | 3674 | 3692 | 3711 | 3729 | 3747 | 3766 | 3784 | 2 | 4 | 6 | 7 | 9 | 11 | 13 | 15 | 17 |
| 24 | 3802 | 3820 | 3838 | 3856 | 3874 | 3892 | 3909 | 3927 | 3945 | 3962 | 2 | 4 | 5 | 7 | 9 | 11 | 12 | 14 | 16 |
| 25 | 3979 | 3997 | 4014 | 4031 | 4048 | 4065 | 4082 | 4099 | 4116 | 4133 | 2 | 3 | 5 | 7 | 9 | 10 | 12 | 14 | 15 |
| 26 | 4150 | 4166 | 4183 | 4200 | 4216 | 4232 | 4249 | 4265 | 4281 | 4298 | 2 | 3 | 5 | 7 | 8 | 10 | 11 | 13 | 15 |
| 27 | 4314 | 4330 | 4346 | 4362 | 4378 | 4393 | 4409 | 4425 | 4440 | 4456 | 2 | 3 | 5 | 6 | 8 | 9 | 11 | 13 | 14 |
| 28 | 4472 | 4487 | 4502 | 4518 | 4533 | 4548 | 4564 | 4579 | 4594 | 4609 | 2 | 3 | 5 | 6 | 8 | 9 | 11 | 12 | 14 |
| 29 | 4624 | 4639 | 4654 | 4669 | 4683 | 4698 | 4713 | 4728 | 4742 | 4757 | 1 | 3 | 4 | 6 | 7 | 9 | 10 | 12 | 13 |
| 30 | 4771 | 4786 | 4800 | 4814 | 4829 | 4843 | 4857 | 4871 | 4886 | 4900 | 1 | 3 | 4 | 6 | 7 | 9 | 10 | 11 | 13 |
| 31 | 4914 | 4928 | 4942 | 4955 | 4969 | 4983 | 4997 | 5011 | 5024 | 5038 | 1 | 3 | 4 | 6 | 7 | 8 | 10 | 11 | 12 |
| 32 | 5051 | 5065 | 5079 | 5092 | 5105 | 5119 | 5132 | 5145 | 5159 | 5172 | 1 | 3 | 4 | 5 | 7 | 8 | 9 | 11 | 12 |
| 33 | 5185 | 5198 | 5211 | 5224 | 5237 | 5250 | 5263 | 5276 | 5289 | 5302 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 12 |
| 34 | 5315 | 5328 | 5340 | 5353 | 5366 | 5378 | 5391 | 5403 | 5416 | 5428 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 |
| 35 | 5441 | 5453 | 5465 | 5478 | 5490 | 5502 | 5514 | 5527 | 5539 | 5551 | 1 | 2 | 4 | 5 | 6 | 7 | 9 | 10 | 11 |
| 36 | 5563 | 5575 | 5587 | 5599 | 5611 | 5623 | 5635 | 5647 | 5658 | 5670 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 10 | 11 |
| 37 | 5682 | 5694 | 5705 | 5717 | 5729 | 5740 | 5752 | 5763 | 5775 | 5786 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 9 | 10 |
| 38 | 5798 | 5809 | 5821 | 5832 | 5843 | 5855 | 5866 | 5877 | 5888 | 5899 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 9 | 10 |
| 39 | 5911 | 5922 | 5933 | 5944 | 5955 | 5966 | 5977 | 5988 | 5999 | 6010 | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 |
| 40 | 6021 | 6031 | 6042 | 6053 | 6064 | 6075 | 6085 | 6096 | 6107 | 6117 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| 41 | 6128 | 6138 | 6149 | 6160 | 6170 | 6180 | 6191 | 6201 | 6212 | 6222 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 42 | 6232 | 6243 | 6253 | 6263 | 6274 | 6284 | 6294 | 6304 | 6314 | 6325 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 43 | 6335 | 6345 | 6355 | 6365 | 6375 | 6385 | 6395 | 6405 | 6415 | 6425 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 44 | 6435 | 6444 | 6454 | 6464 | 6474 | 6484 | 6493 | 6503 | 6513 | 6522 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 45 | 6532 | 6542 | 6551 | 6561 | 6571 | 6580 | 6590 | 6599 | 6609 | 6618 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 46 | 6628 | 6637 | 6646 | 6656 | 6665 | 6675 | 6684 | 6693 | 6702 | 6712 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 7 | 8 |
| 47 | 6721 | 6730 | 6739 | 6749 | 6758 | 6767 | 6776 | 6785 | 6794 | 6803 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 8 |
| 48 | 6812 | 6821 | 6830 | 6839 | 6848 | 6857 | 6866 | 6875 | 6884 | 6893 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 |
| 49 | 6902 | 6911 | 6920 | 6928 | 6937 | 6946 | 6955 | 6964 | 6972 | 6981 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 |
| 50 | 6990 | 6998 | 7007 | 7016 | 7024 | 7033 | 7042 | 7050 | 7059 | 7067 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 |

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## MATHEMATICAL TABLES.

### Logarithms.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 7076 | 7084 | 7093 | 7101 | 7110 | 7118 | 7126 | 7135 | 7143 | 7152 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 |
| 52 | 7160 | 7168 | 7177 | 7185 | 7193 | 7202 | 7210 | 7218 | 7226 | 7235 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 | 7 |
| 53 | 7243 | 7251 | 7259 | 7267 | 7275 | 7284 | 7292 | 7300 | 7308 | 7316 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 6 | 7 |
| 54 | 7324 | 7332 | 7340 | 7348 | 7356 | 7364 | 7372 | 7380 | 7388 | 7396 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 6 | 7 |
| 55 | 7404 | 7412 | 7419 | 7427 | 7435 | 7443 | 7451 | 7459 | 7466 | 7474 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| 56 | 7482 | 7490 | 7497 | 7505 | 7513 | 7520 | 7528 | 7536 | 7543 | 7551 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| 57 | 7559 | 7566 | 7574 | 7582 | 7589 | 7597 | 7604 | 7612 | 7619 | 7627 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| 58 | 7634 | 7642 | 7649 | 7657 | 7664 | 7672 | 7679 | 7686 | 7694 | 7701 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 |
| 59 | 7709 | 7716 | 7723 | 7731 | 7738 | 7745 | 7752 | 7760 | 7767 | 7774 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 |
| 60 | 7782 | 7789 | 7796 | 7803 | 7810 | 7818 | 7825 | 7832 | 7839 | 7846 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 6 |
| 61 | 7853 | 7860 | 7868 | 7875 | 7882 | 7889 | 7896 | 7903 | 7910 | 7917 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 6 |
| 62 | 7924 | 7931 | 7938 | 7945 | 7952 | 7959 | 7966 | 7973 | 7980 | 7987 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 6 |
| 63 | 7993 | 8000 | 8007 | 8014 | 8021 | 8028 | 8035 | 8041 | 8048 | 8055 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 |
| 64 | 8062 | 8069 | 8075 | 8082 | 8089 | 8096 | 8102 | 8109 | 8116 | 8122 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 |
| 65 | 8129 | 8136 | 8142 | 8149 | 8156 | 8162 | 8169 | 8176 | 8182 | 8189 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 |
| 66 | 8195 | 8202 | 8209 | 8215 | 8222 | 8228 | 8235 | 8241 | 8248 | 8254 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 |
| 67 | 8261 | 8267 | 8274 | 8280 | 8287 | 8293 | 8299 | 8306 | 8312 | 8319 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 |
| 68 | 8325 | 8331 | 8338 | 8344 | 8351 | 8357 | 8363 | 8370 | 8376 | 8382 | 1 | 1 | 2 | 3 | 3 | 4 | 4 | 5 | 6 |
| 69 | 8388 | 8395 | 8401 | 8407 | 8414 | 8420 | 8426 | 8432 | 8439 | 8445 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 6 |
| 70 | 8451 | 8457 | 8463 | 8470 | 8476 | 8482 | 8488 | 8494 | 8500 | 8506 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 6 |
| 71 | 8513 | 8519 | 8525 | 8531 | 8537 | 8543 | 8549 | 8555 | 8561 | 8567 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 5 |
| 72 | 8573 | 8579 | 8585 | 8591 | 8597 | 8603 | 8609 | 8615 | 8621 | 8627 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 5 |
| 73 | 8633 | 8639 | 8645 | 8651 | 8657 | 8663 | 8669 | 8675 | 8681 | 8686 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 5 |
| 74 | 8692 | 8698 | 8704 | 8710 | 8716 | 8722 | 8727 | 8733 | 8739 | 8745 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 5 |
| 75 | 8751 | 8756 | 8762 | 8768 | 8774 | 8779 | 8785 | 8791 | 8797 | 8802 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 5 | 5 |
| 76 | 8808 | 8814 | 8820 | 8825 | 8831 | 8837 | 8842 | 8848 | 8854 | 8859 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 5 | 5 |
| 77 | 8865 | 8871 | 8876 | 8882 | 8887 | 8893 | 8899 | 8904 | 8910 | 8915 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 78 | 8921 | 8927 | 8932 | 8938 | 8943 | 8949 | 8954 | 8960 | 8965 | 8971 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 79 | 8976 | 8982 | 8987 | 8993 | 8998 | 9004 | 9009 | 9015 | 9020 | 9025 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 80 | 9031 | 9036 | 9042 | 9047 | 9053 | 9058 | 9063 | 9069 | 9074 | 9079 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 81 | 9085 | 9090 | 9096 | 9101 | 9106 | 9112 | 9117 | 9122 | 9128 | 9133 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 82 | 9138 | 9143 | 9149 | 9154 | 9159 | 9165 | 9170 | 9175 | 9180 | 9186 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 83 | 9191 | 9196 | 9201 | 9206 | 9212 | 9217 | 9222 | 9227 | 9232 | 9238 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 84 | 9243 | 9248 | 9253 | 9258 | 9263 | 9269 | 9274 | 9279 | 9284 | 9289 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 85 | 9294 | 9299 | 9304 | 9309 | 9315 | 9320 | 9325 | 9330 | 9335 | 9340 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 86 | 9345 | 9350 | 9355 | 9360 | 9365 | 9370 | 9375 | 9380 | 9385 | 9390 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| 87 | 9395 | 9400 | 9405 | 9410 | 9415 | 9420 | 9425 | 9430 | 9435 | 9440 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 88 | 9445 | 9450 | 9455 | 9460 | 9465 | 9469 | 9474 | 9479 | 9484 | 9489 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 89 | 9494 | 9499 | 9504 | 9509 | 9513 | 9518 | 9523 | 9528 | 9533 | 9538 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 90 | 9542 | 9547 | 9552 | 9557 | 9562 | 9566 | 9571 | 9576 | 9581 | 9586 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 91 | 9590 | 9595 | 9600 | 9605 | 9609 | 9614 | 9619 | 9624 | 9628 | 9633 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 92 | 9638 | 9643 | 9647 | 9652 | 9657 | 9661 | 9666 | 9671 | 9675 | 9680 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 93 | 9685 | 9689 | 9694 | 9699 | 9703 | 9708 | 9713 | 9717 | 9722 | 9727 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 94 | 9731 | 9736 | 9741 | 9745 | 9750 | 9754 | 9759 | 9763 | 9768 | 9773 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 95 | 9777 | 9782 | 9786 | 9791 | 9795 | 9800 | 9805 | 9809 | 9814 | 9818 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 96 | 9823 | 9827 | 9832 | 9836 | 9841 | 9845 | 9850 | 9854 | 9859 | 9863 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 97 | 9868 | 9872 | 9877 | 9881 | 9886 | 9890 | 9894 | 9899 | 9903 | 9908 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 98 | 9912 | 9917 | 9921 | 9926 | 9930 | 9934 | 9939 | 9943 | 9948 | 9952 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| 99 | 9956 | 9961 | 9965 | 9969 | 9974 | 9978 | 9983 | 9987 | 9991 | 9996 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 4 |

## ANTILOGARITHMS.

|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ·00 | 1000 | 1002 | 1005 | 1007 | 1009 | 1012 | 1014 | 1016 | 1019 | 1021 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| ·01 | 1023 | 1026 | 1028 | 1030 | 1033 | 1035 | 1038 | 1040 | 1042 | 1045 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| ·02 | 1017 | 1050 | 1052 | 1054 | 1057 | 1059 | 1062 | 1064 | 1067 | 1069 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| ·03 | 1072 | 1074 | 1076 | 1079 | 1081 | 1084 | 1086 | 1089 | 1091 | 1094 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| ·04 | 1096 | 1099 | 1102 | 1104 | 1107 | 1109 | 1112 | 1114 | 1117 | 1119 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| ·05 | 1122 | 1125 | 1127 | 1130 | 1132 | 1135 | 1138 | 1140 | 1143 | 1146 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| ·06 | 1148 | 1151 | 1153 | 1156 | 1159 | 1161 | 1164 | 1167 | 1169 | 1172 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| ·07 | 1175 | 1178 | 1180 | 1183 | 1186 | 1189 | 1191 | 1194 | 1197 | 1199 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| ·08 | 1202 | 1205 | 1208 | 1211 | 1213 | 1216 | 1219 | 1222 | 1225 | 1227 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 |
| ·09 | 1230 | 1233 | 1236 | 1239 | 1242 | 1245 | 1247 | 1250 | 1253 | 1256 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 |
| ·10 | 1259 | 1262 | 1265 | 1268 | 1271 | 1274 | 1276 | 1279 | 1282 | 1285 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 |
| ·11 | 1288 | 1291 | 1294 | 1297 | 1300 | 1303 | 1306 | 1309 | 1312 | 1315 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 3 |
| ·12 | 1318 | 1321 | 1324 | 1327 | 1330 | 1331 | 1337 | 1340 | 1343 | 1346 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 3 |
| ·13 | 1349 | 1352 | 1355 | 1358 | 1361 | 1365 | 1368 | 1371 | 1374 | 1377 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 |
| ·14 | 1380 | 1384 | 1387 | 1390 | 1393 | 1396 | 1400 | 1403 | 1406 | 1409 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 |
| ·15 | 1413 | 1416 | 1419 | 1422 | 1426 | 1429 | 1432 | 1435 | 1439 | 1442 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 |
| ·16 | 1445 | 1449 | 1452 | 1455 | 1459 | 1462 | 1466 | 1469 | 1472 | 1476 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 |
| ·17 | 1479 | 1483 | 1486 | 1489 | 1493 | 1496 | 1500 | 1503 | 1507 | 1510 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 |
| ·18 | 1514 | 1517 | 1521 | 1524 | 1528 | 1531 | 1535 | 1538 | 1542 | 1545 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 |
| ·19 | 1549 | 1552 | 1556 | 1560 | 1563 | 1567 | 1570 | 1574 | 1578 | 1581 | 0 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 |
| ·20 | 1585 | 1589 | 1592 | 1596 | 1600 | 1603 | 1607 | 1611 | 1614 | 1618 | 0 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 |
| ·21 | 1622 | 1626 | 1629 | 1633 | 1637 | 1641 | 1644 | 1648 | 1652 | 1656 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 |
| ·22 | 1660 | 1663 | 1667 | 1671 | 1675 | 1679 | 1683 | 1687 | 1690 | 1694 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 |
| ·23 | 1698 | 1702 | 1706 | 1710 | 1714 | 1718 | 1722 | 1726 | 1730 | 1734 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 4 |
| ·24 | 1738 | 1742 | 1746 | 1750 | 1754 | 1758 | 1762 | 1766 | 1770 | 1774 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 4 |
| ·25 | 1778 | 1782 | 1786 | 1791 | 1795 | 1799 | 1803 | 1807 | 1811 | 1816 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 4 |
| ·26 | 1820 | 1824 | 1828 | 1832 | 1837 | 1841 | 1845 | 1849 | 1854 | 1858 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 4 |
| ·27 | 1863 | 1866 | 1871 | 1875 | 1879 | 1884 | 1888 | 1892 | 1897 | 1901 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 4 |
| ·28 | 1905 | 1910 | 1914 | 1919 | 1923 | 1928 | 1932 | 1936 | 1941 | 1945 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| ·29 | 1950 | 1954 | 1959 | 1963 | 1968 | 1972 | 1977 | 1982 | 1986 | 1991 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| ·30 | 1995 | 2000 | 2004 | 2009 | 2014 | 2018 | 2023 | 2028 | 2032 | 2037 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| ·31 | 2042 | 2046 | 2051 | 2056 | 2061 | 2065 | 2070 | 2075 | 2080 | 2084 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| ·32 | 2089 | 2094 | 2099 | 2104 | 2109 | 2113 | 2118 | 2123 | 2128 | 2133 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| ·33 | 2138 | 2143 | 2148 | 2153 | 2158 | 2163 | 2168 | 2173 | 2178 | 2183 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| ·34 | 2188 | 2193 | 2198 | 2203 | 2208 | 2213 | 2218 | 2223 | 2228 | 2234 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| ·35 | 2239 | 2244 | 2249 | 2254 | 2259 | 2265 | 2270 | 2275 | 2280 | 2286 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| ·36 | 2291 | 2296 | 2301 | 2307 | 2312 | 2317 | 2323 | 2328 | 2333 | 2339 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| ·37 | 2344 | 2350 | 2355 | 2360 | 2366 | 2371 | 2377 | 2382 | 2388 | 2393 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| ·38 | 2399 | 2404 | 2410 | 2415 | 2421 | 2427 | 2432 | 2438 | 2443 | 2449 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| ·39 | 2455 | 2460 | 2466 | 2472 | 2477 | 2483 | 2489 | 2495 | 2500 | 2506 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 5 | 5 |
| ·40 | 2512 | 2518 | 2523 | 2529 | 2535 | 2541 | 2547 | 2553 | 2559 | 2564 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 5 |
| ·41 | 2570 | 2576 | 2582 | 2588 | 2594 | 2600 | 2606 | 2612 | 2618 | 2624 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 5 |
| ·42 | 2630 | 2636 | 2642 | 2649 | 2655 | 2661 | 2667 | 2673 | 2679 | 2685 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 6 |
| ·43 | 2692 | 2698 | 2704 | 2710 | 2716 | 2723 | 2729 | 2735 | 2742 | 2748 | 1 | 1 | 2 | 3 | 3 | 4 | 4 | 5 | 6 |
| ·44 | 2754 | 2761 | 2767 | 2773 | 2780 | 2786 | 2793 | 2799 | 2805 | 2812 | 1 | 1 | 2 | 3 | 3 | 4 | 4 | 5 | 6 |
| ·45 | 2818 | 2825 | 2831 | 2838 | 2844 | 2851 | 2858 | 2864 | 2871 | 2877 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 |
| ·46 | 2884 | 2891 | 2897 | 2904 | 2911 | 2917 | 2924 | 2931 | 2938 | 2944 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 |
| ·47 | 2951 | 2958 | 2965 | 2972 | 2979 | 2985 | 2992 | 2999 | 3006 | 3013 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 |
| ·48 | 3020 | 3027 | 3034 | 3041 | 3048 | 3055 | 3062 | 3069 | 3076 | 3083 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 6 |
| ·49 | 3090 | 3097 | 3105 | 3112 | 3119 | 3126 | 3133 | 3141 | 3148 | 3155 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 6 |

## ANTILOGARITHMS.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ·50 | 3162 | 3170 | 3177 | 3184 | 3192 | 3199 | 3206 | 3214 | 3221 | 3228 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 |
| ·51 | 3236 | 3243 | 3251 | 3258 | 3266 | 3273 | 3281 | 3289 | 3296 | 3304 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| ·52 | 3311 | 3319 | 3327 | 3334 | 3342 | 3350 | 3357 | 3365 | 3373 | 3381 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| ·53 | 3388 | 3396 | 3404 | 3412 | 3420 | 3428 | 3436 | 3443 | 3451 | 3459 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 6 | 7 |
| ·54 | 3467 | 3475 | 3483 | 3491 | 3499 | 3508 | 3516 | 3524 | 3532 | 3540 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 6 | 7 |
| ·55 | 3548 | 3556 | 3565 | 3573 | 3581 | 3589 | 3597 | 3606 | 3614 | 3622 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 | 7 |
| ·56 | 3631 | 3639 | 3648 | 3656 | 3664 | 3673 | 3681 | 3690 | 3698 | 3707 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 |
| ·57 | 3715 | 3724 | 3733 | 3741 | 3750 | 3758 | 3767 | 3776 | 3784 | 3793 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 8 |
| ·58 | 3802 | 3811 | 3819 | 3828 | 3837 | 3846 | 3855 | 3864 | 3873 | 3882 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 8 |
| ·59 | 3890 | 3899 | 3908 | 3917 | 3926 | 3936 | 3945 | 3954 | 3963 | 3972 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 8 |
| ·60 | 3981 | 3990 | 3999 | 4009 | 4018 | 4027 | 4036 | 4046 | 4055 | 4064 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 8 |
| ·61 | 4074 | 4083 | 4093 | 4102 | 4111 | 4121 | 4130 | 4140 | 4150 | 4159 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| ·62 | 4169 | 4178 | 4188 | 4198 | 4207 | 4217 | 4227 | 4236 | 4246 | 4256 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| ·63 | 4266 | 4276 | 4285 | 4295 | 4305 | 4315 | 4325 | 4335 | 4345 | 4355 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| ·64 | 4365 | 4375 | 4385 | 4395 | 4406 | 4416 | 4426 | 4436 | 4446 | 4457 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| ·65 | 4467 | 4477 | 4487 | 4498 | 4508 | 4519 | 4529 | 4539 | 4550 | 4560 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| ·66 | 4571 | 4581 | 4592 | 4603 | 4613 | 4624 | 4634 | 4645 | 4656 | 4667 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 10 |
| ·67 | 4677 | 4688 | 4699 | 4710 | 4721 | 4732 | 4742 | 4753 | 4764 | 4775 | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 |
| ·68 | 4786 | 4797 | 4808 | 4819 | 4831 | 4842 | 4853 | 4864 | 4875 | 4887 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 |
| ·69 | 4898 | 4909 | 4920 | 4932 | 4943 | 4955 | 4966 | 4977 | 4989 | 5000 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 9 | 10 |
| ·70 | 5012 | 5023 | 5035 | 5047 | 5058 | 5070 | 5082 | 5093 | 5105 | 5117 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 11 |
| ·71 | 5129 | 5140 | 5152 | 5164 | 5176 | 5188 | 5200 | 5212 | 5224 | 5236 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 10 | 11 |
| ·72 | 5248 | 5260 | 5272 | 5284 | 5297 | 5309 | 5321 | 5333 | 5346 | 5358 | 1 | 2 | 4 | 5 | 6 | 7 | 9 | 10 | 11 |
| ·73 | 5370 | 5383 | 5395 | 5408 | 5420 | 5433 | 5445 | 5458 | 5470 | 5483 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 |
| ·74 | 5495 | 5508 | 5521 | 5534 | 5546 | 5559 | 5572 | 5585 | 5598 | 5610 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 12 |
| ·75 | 5623 | 5636 | 5649 | 5662 | 5675 | 5689 | 5702 | 5715 | 5728 | 5741 | 1 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 12 |
| ·76 | 5754 | 5768 | 5781 | 5794 | 5808 | 5821 | 5834 | 5848 | 5861 | 5875 | 1 | 3 | 4 | 5 | 7 | 8 | 9 | 11 | 12 |
| ·77 | 5888 | 5902 | 5916 | 5929 | 5943 | 5957 | 5970 | 5984 | 5998 | 6012 | 1 | 3 | 4 | 5 | 7 | 8 | 10 | 11 | 12 |
| ·78 | 6026 | 6039 | 6053 | 6067 | 6081 | 6095 | 6109 | 6124 | 6138 | 6152 | 1 | 3 | 4 | 6 | 7 | 8 | 10 | 11 | 13 |
| ·79 | 6166 | 6180 | 6194 | 6209 | 6223 | 6237 | 6252 | 6266 | 6281 | 6295 | 1 | 3 | 4 | 6 | 7 | 9 | 10 | 11 | 13 |
| ·80 | 6310 | 6324 | 6339 | 6353 | 6368 | 6383 | 6397 | 6412 | 6427 | 6442 | 1 | 3 | 4 | 6 | 7 | 9 | 10 | 12 | 13 |
| ·81 | 6457 | 6471 | 6486 | 6501 | 6516 | 6531 | 6546 | 6561 | 6577 | 6592 | 2 | 3 | 5 | 6 | 8 | 9 | 11 | 12 | 14 |
| ·82 | 6607 | 6622 | 6637 | 6653 | 6668 | 6683 | 6699 | 6714 | 6730 | 6745 | 2 | 3 | 5 | 6 | 8 | 9 | 11 | 12 | 14 |
| ·83 | 6761 | 6776 | 6792 | 6808 | 6823 | 6839 | 6855 | 6871 | 6887 | 6902 | 2 | 3 | 5 | 6 | 8 | 9 | 11 | 13 | 14 |
| ·84 | 6918 | 6934 | 6950 | 6966 | 6982 | 6998 | 7015 | 7031 | 7047 | 7063 | 2 | 3 | 5 | 6 | 8 | 10 | 11 | 13 | 15 |
| ·85 | 7079 | 7096 | 7112 | 7129 | 7145 | 7161 | 7178 | 7194 | 7211 | 7228 | 2 | 3 | 5 | 7 | 8 | 10 | 12 | 13 | 15 |
| ·86 | 7244 | 7261 | 7278 | 7295 | 7311 | 7328 | 7345 | 7362 | 7379 | 7396 | 2 | 3 | 5 | 7 | 8 | 10 | 12 | 13 | 15 |
| ·87 | 7413 | 7430 | 7447 | 7464 | 7482 | 7499 | 7516 | 7534 | 7551 | 7568 | 2 | 3 | 5 | 7 | 9 | 10 | 12 | 14 | 16 |
| ·88 | 7586 | 7603 | 7621 | 7638 | 7656 | 7674 | 7691 | 7709 | 7727 | 7745 | 2 | 4 | 5 | 7 | 9 | 11 | 12 | 14 | 16 |
| ·89 | 7762 | 7780 | 7798 | 7816 | 7834 | 7852 | 7870 | 7889 | 7907 | 7925 | 2 | 4 | 5 | 7 | 9 | 11 | 13 | 14 | 16 |
| ·90 | 7943 | 7962 | 7980 | 7998 | 8017 | 8035 | 8054 | 8072 | 8091 | 8110 | 2 | 4 | 6 | 7 | 9 | 11 | 13 | 15 | 17 |
| ·91 | 8128 | 8147 | 8166 | 8185 | 8204 | 8222 | 8241 | 8260 | 8279 | 8299 | 2 | 4 | 6 | 8 | 9 | 11 | 13 | 15 | 17 |
| ·92 | 8318 | 8337 | 8356 | 8375 | 8395 | 8414 | 8433 | 8453 | 8472 | 8492 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 15 | 17 |
| ·93 | 8511 | 8531 | 8551 | 8570 | 8590 | 8610 | 8630 | 8650 | 8670 | 8690 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |
| ·94 | 8710 | 8730 | 8750 | 8770 | 8790 | 8810 | 8831 | 8851 | 8872 | 8892 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |
| ·95 | 8913 | 8933 | 8954 | 8974 | 8995 | 9016 | 9036 | 9057 | 9078 | 9099 | 2 | 4 | 6 | 8 | 10 | 12 | 15 | 17 | 19 |
| ·96 | 9120 | 9141 | 9162 | 9183 | 9204 | 9226 | 9247 | 9268 | 9290 | 9311 | 2 | 4 | 6 | 8 | 11 | 13 | 15 | 17 | 19 |
| ·97 | 9333 | 9354 | 9376 | 9397 | 9419 | 9441 | 9462 | 9484 | 9506 | 9528 | 2 | 4 | 7 | 9 | 11 | 13 | 15 | 17 | 20 |
| ·98 | 9550 | 9572 | 9594 | 9616 | 9638 | 9661 | 9683 | 9705 | 9727 | 9750 | 2 | 4 | 7 | 9 | 11 | 13 | 16 | 18 | 20 |
| ·99 | 9772 | 9795 | 9817 | 9840 | 9863 | 9886 | 9908 | 9931 | 9954 | 9977 | 2 | 5 | 7 | 9 | 11 | 14 | 16 | 18 | 20 |

## Table VII.

## TRIGONOMETRICAL RATIOS, &c.

| Angle. | Radians. | Sine. | Tangent. | Co-tangent. | Cosine. | | |
|---|---|---|---|---|---|---|---|
| 0° | 0 | 0 | 0 | ∝ | 1 | 1·5708 | 90° |
| 1 | ·0175 | ·0175 | ·0175 | 57·2900 | ·9998 | 1·5533 | 89 |
| 2 | ·0349 | ·0349 | ·0349 | 28·6363 | ·9994 | 1·5359 | 88 |
| 3 | ·0524 | ·0523 | ·0524 | 19·0811 | ·9986 | 1·5184 | 87 |
| 4 | ·0698 | ·0698 | ·0699 | 14·3007 | ·9976 | 1·5010 | 86 |
| 5 | ·0873 | ·0872 | ·0875 | 11·4301 | ·9962 | 1·4835 | 85 |
| 6 | ·1047 | ·1045 | ·1051 | 9·5144 | ·9945 | 1·4661 | 84 |
| 7 | ·1222 | ·1219 | ·1228 | 8·1443 | ·9925 | 1·4486 | 83 |
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# APPENDIX E.

## RESUSCITATION FROM APPARENT DEATH BY ELECTRIC SHOCK.

The urgent necessity for prompt and persistent efforts at resuscitation of victims of accidental shocks by electricity is very well emphasised by the successful results in the instances recorded. In order that the task may not be undertaken in a half-hearted manner, it must be appreciated that accidental shocks seldom result in absolute death unless the victim is left unaided too long, or efforts at resuscitation are stopped too early.

In the majority of instances the shock is only sufficient to suspend animation temporarily, owing to the momentary and imperfect contact of the conductors, and also on account of the resistance of the body submitted to the influence of the current. It must be appreciated also that the body under the conditions of accidental shocks seldom receives the full force of the current in the circuit, but only a shunt current, which may represent a very insignificant part of the whole.

When an accident occurs, the following rules should be promptly executed with care and deliberation pending the arrival of a doctor :—

(1) Remove the body at once from the circuit by breaking contact with the conductors. This may be accomplished by using a dry stick of wood, which is a non-conductor, to roll the body over to one side, or to brush aside a wire if that is conveying the current. When a stick is not at hand, any dry piece of clothing may be utilised to protect the hand in seizing the body of the victim, unless rubber gloves are available. If the body is in contact with the earth the coat tails of the victim, or any loose or detached piece of clothing may be seized with impunity to draw it away from the conductor. When this has been accomplished, observe rule 2. The object to be attained is to make the subject breathe, and if this can be accomplished and continued he can be saved.

(2) Lay the man on the ground, face downwards. Turn his head on one side. No time should be lost by removing or loosening clothes. Begin artificial respiration at once. Tell one of the bystanders to prepare some sort of pad like a folded coat and slip it in under the patient's body just above his waist; but do not wait for this. You will probably have performed several movements of respiration before the pad is ready and have thus gained all-valuable time. Kneel by the patient's side or across his body facing his head. Spread your hands out flat on his back at his lowest ribs. Press gradually and slowly for about three seconds by leaning forward on to your hands. Use no violence. Relax the pressure by falling back into your original upright kneeling position for two seconds. The process of artificial respiration consists in repeating this swaying motion backwards and forwards about 12 to 15 times a minute.

(3) The dashing of cold water into the face will sometimes produce a gasp and start breathing, which should then be continued as directed above. If this is not successful the spine should be rubbed vigorously with a piece of ice. Alternate applications of heat and cold over the region of the heart will accomplish the same object in some instances. It is both useless and unwise to attempt to administer stimulants to the victim in the usual manner by pouring them down his throat.

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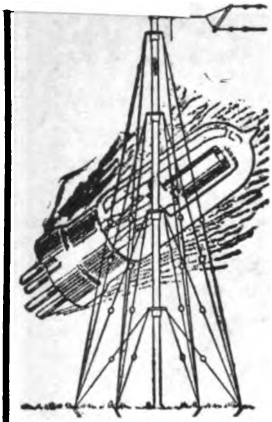

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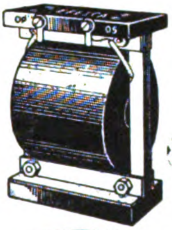

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